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FUNCTIONAL SPECIFICATIONS OF LINCOLN LABORATORY ORBIT DETERMINATION PROGRAMS

10 MAY 1966

Prepared for

Massachusetts Institute of Technology
Lincoln Laboratory

Under Contract No. BB 202
Prime Contract AF 19 (628)-5167

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INTRODUCTION

This document describes the orbit determination programs and data processing programs developed by TRW Systems for the Lincoln Laboratory Millstone Hill radar. These programs provide the SDS 9300 computer associated with the radar with the following capabilities: satellite orbit prediction, antenna steering, data and editing averaging, and differential correction of the orbit elements. The programs that support the radar during a tracking operation are fully automatic, under the control of the radar hardware and the operator's console. They perform sufficiently fast to permit their use during a radar tracking pass and, thereby, provide real time orbit determination capabilities in supporting the tracker. This facility is accomplished by partitioning the orbit determination functions into those which can be performed before the pass, after the pass, and doing only the absolute minimum processing during the pass. The capabilities in the real time programs (MHESPOD) have been also provided in a stand alone support program for nonreal time use (NRTPOD).

The processing done before the pass takes available orbital elements for the satellite and derives from them a steering ephemeris for the radar. At the same time program constants are placed on the steering control tape to control the data averaging and differential correction processes during the pass. This tape is mounted on the SDS Magpac unit minutes prior to the pass. During the pass a processor interpolates the steering ephemeris and causes the antenna to be steered toward the nominal path of the satellite. The radar operator can manually superimpose a search pattern upon the nominal steering pattern to aid acquisition. The first observations of the spacecraft enter a preliminary correction process to cause the antenna to be steered toward the point displaced up or down the nominal trajectory by the actually observed time lag or time advance. Upon operator control tracking data are averaged and stored in core for use in real time differential correction and recorded on magnetic tape for later use. Upon operator control the differential correction is performed and a new steering ephemeris is generated for the observed satellite. All residuals, old elements, new elements, and certain derived quantities are recorded on magnetic tape for later printout and processing.

A minimum of monitoring printout is provided. After the pass the details of the differential correction may be listed for review, the new steering ephemeris may be listed for review, and the data taken on the current pass may be adapted for use as a priori information on a subsequent pass.

The program modules constituting this orbit determination and data processing system are designated as follows:

<u>DAP</u>

DAP edits and averages raw radar returns and records the raw and/or averaged data on magnetic tape for later use.

<u>PREMOD</u>

PREMOD updates the available orbital elements to an epoch immediately preceding the pass of interest and creates the steering ephemeris.

<u>LAP</u>

LAP interpolates the steering ephemeris and provides look angles to the radar.

<u>MHESPOD</u>

MHESPOD is a real time differential correction program which improves the orbital estimate of the vehicle and generates a new steering ephemeris.

<u>NRTPOD</u>

NRTPOD is a comprehensive off-line orbit determination and differential correction program for general use.

The foregoing program modules were written specifically for operation at the Millstone Hill radar site and observe contraints inherent in that operation and within the SDS 9300 computer. However, they were written in the FORTRAN IV, Version 12 programing language and can be adapted for use on compatible computer systems.

Accepted for the Air Force
Franklin C. Hudson
Chief, Lincoln Laboratory Office

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1. PREMOD-MHESPOD

1.1 GENERAL DESCRIPTION

PREMOD

PREMOD is the Preparation Module used in conjunction with the Millstone Hill version of ESPOD (MHESPOD), the Data Averaging Program (DAP), and the Look Angle Program (LAP). PREMOD allows communication between the analyst and each of these real time modules.

In non-real time orbit determination programs (e.g., ESPOD) a large portion of the memory space of the program is devoted to the task of processing the input data. Another function of the non-real time program is the preparation of one or more formatted output tapes to record what might be termed peripheral output results, such as the magnitude of the observational residuals, the normal matrix from iteration to iteration, etc. Each of these functions increases not only the memory space required for the operation of the program but also the running time of the program. In a real time environment the generation of the formatted output is most efficiently done as a post-exercise function, and similarly the input data processing can be a pre-exercise function. PREMOD was written to handle each of these tasks.

The DAP program will accept console commands to control its internal processing and, additionally, the analyst can specify a number of parameters related to the actual editing of the raw data from the antennas. These central parameters are accepted as card input to PREMOD and communicated to DAP through the Before Conditioning Tape (BCT). This tape contains all the input data for DAP, LAP, and MHESPOD and is generated before the tracking exercise is to begin.

As DAP receives the raw tracking data, it will on option record this data on a high speed magnetic tape. If data is to be averaged by DAP, the averaged data may also be recorded on the magnetic tape. PREMOD will accept this DAP tape as input and prepare a printed output of both the raw and averaged data.

PREMOD prepares for LAP the look angle ephemeris of the spacecraft relative to Millstone Hill. The ephemeris contains 60 equally spaced entries of time, range, azimuth, elevation, and either:

a) $\dot{R}, \frac{\partial R}{\partial t}, \frac{\partial A}{\partial t}, \frac{\partial E}{\partial t}$ or

b) $\ddot{R}, \dot{R}, \dot{A}, \dot{E}$

The former a) is used by DAP to adjust the epoch time associated with the SPADATS 6-card element set, and the latter (b) is used in the interpolation for steering data. The look angle ephemeris is placed by PREMOD on the BCT.

PREMOD performs three functions for MHESPOD. It is the input processor, it is an output post-processor, and it performs a restart function using the After Differential correction Tape (ADT) generated by MHESPOD. PREMOD processes all the input parameters to MHESPOD and prepares a data storage (COMMON) record for the BCT. Included among the MHESPOD inputs are:

a) The best estimate of the initial conditions of the orbit

b) The specification of the force model to be used in the trajectory simulation

c) Additional tracking station data and observations

d) Specification of the desired epoch to be used in the MHESPOD fit

e) Control information regarding the output placed on the ADT.

PREMOD will propagate the input initial conditions together with the corresponding normal matrix (if any) forward in time to any specific point or on option to the time of the next rise of this satellite relative to Millstone Hill. (Rise is defined as elevation angle greater than -1.5 degrees.)

The ephemeris of the sun and moon which is input on cards to PREMOD relative to the mean equator and equinox of 1950.0 is precessed to the final epoch time established, and any station location and observation cards are processed. The user may specify up to five unique tracking stations (Millstone, Haystack, and Kwajalein are assumed) and any number of pre-sorted observation cards. These observatories are used in MHESPOD on each

iteration after the first and are written on the BCT. For the first iteration, the program assumes an a priori normal matrix associated with the observations input to PREMOD on cards. PREMOD does not itself contain any orbit determination or differential correction capability. It does, however, perform a complete trajectory simulation using a variable step Cowell second sum method including an automatic error detection of earth impact. The MHESPOD trajectory integration routine uses a fixed step method (for speed and simplicity) and it depends on PREMOD for a determination of the proper step size and a check that the initial conditions specified for iteration do not impact the earth.

The second function of PREMOD relative to MHESPOD is to perform a post-processing of the high speed ADT tape generated by MHESPOD. The "ADT print" option of PREMOD allows the analyst to recover the following item after the exercise has been completed:

a) The corrections to x, y, z, $\dot{x}$, $\dot{y}$, $\dot{z}$ and their standard deviations (also available as an on-line output from MHESPOD)

b) The current and predicted RMS of the residual data (also available as an on-line output from MHESPOD)

c) The ATA normal matrix and its inverse, the covariance matrix

d) The observed minus computed residuals in the observational data

e) The look angle ephemeris presented to Millstone following the completion of the MHESPOD fit

f) The number of DAP observations used in each iteration together with the number of pre-epoch observations (also available as on-line output from MHESPOD)

g) The SPADATS mean elements corresponding to the new x, y, z, $\dot{x}$, $\dot{y}$, $\dot{z}$ that are computed at the end of each iteration.

The third use of PREMOD relative to MHESPOD is for the "ADT restart" capability. For this option, PREMOD assumes an ADT tape containing a record of core memory following the final iteration in MHESPOD. PREMOD will upgrade the final elements to the start of the next pass (or any arbitrary time) and will include the DAP observations on the ADT

(which were used in real time for the previous pass) as a priori pre-epoch data. This capability allows the analyst to prepare BCT's from pass to pass with a minimum of card inputs.

The functional logic flow of the PREMOD program follows on the next four pages (Figure 1-1).

MHESPOD

MHESPOD is a special purpose differential correction program which was developed for the Lincoln Laboratory Millstone Hill Radar Site to be used in real time tracking exercises. The program is a derivative of ESPOD, a large scale orbit determination program which was developed for the SPACETRACK/SPADATS Center, Ent Air Force Base, Colorado. In essence, MHESPOD is a specialized version of the differential correction portion of ESPOD.

All necessary inputs to MHESPOD for the execution of a real time differential correction are provided by a magnetic tape, the BCT tape, which is generated by a pre-processing program known as PREMOD. The PREMOD program performs all the necessary operations such as assigning weights to observations, converting input quantities to internal units, etc. This feature enables the MHESPOD program to operate very fast. On-line output of MHESPOD is kept to a minimum to further enhance fast operation.

MHESPOD performs a differential correction on the six variables which define the state vector only; that is, the solution is always a 6 x 6 on the Cartesian components of position and velocity. The solution to the normal equations is unbounded, permitting as large a correction as possible. Also, there is no convergence logic to prevent the execution of a divergent step that is if the RMS on a given iteration is larger than the previous RMS. As in the case of the restricted solution vector, there are no bounds and convergence logic for the sake of operational speed. The iteration-by-iteration output of MHESPOD is written on the ADT tape. The PREMOD program can be used to post-process the ADT tape and to obtain the printed output.

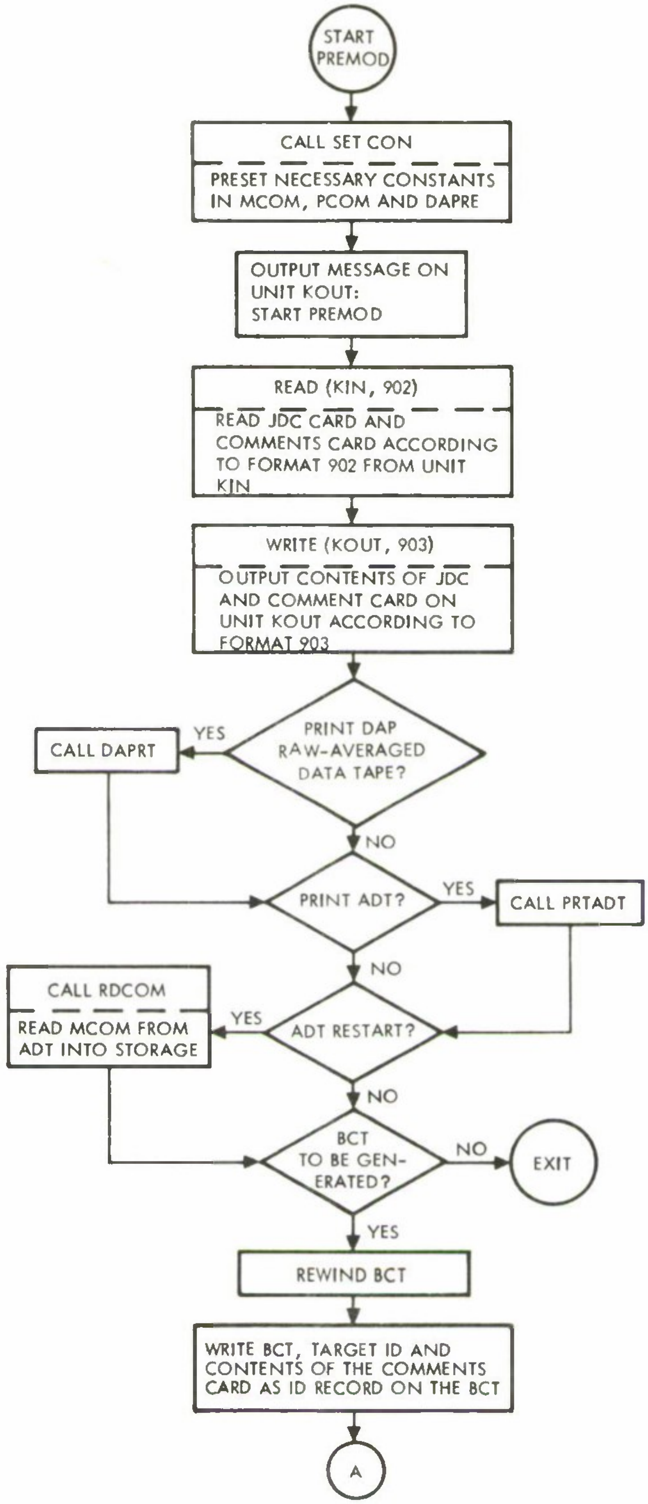


Figure 1-1. Functional Logic Flow of the PREMOD Program

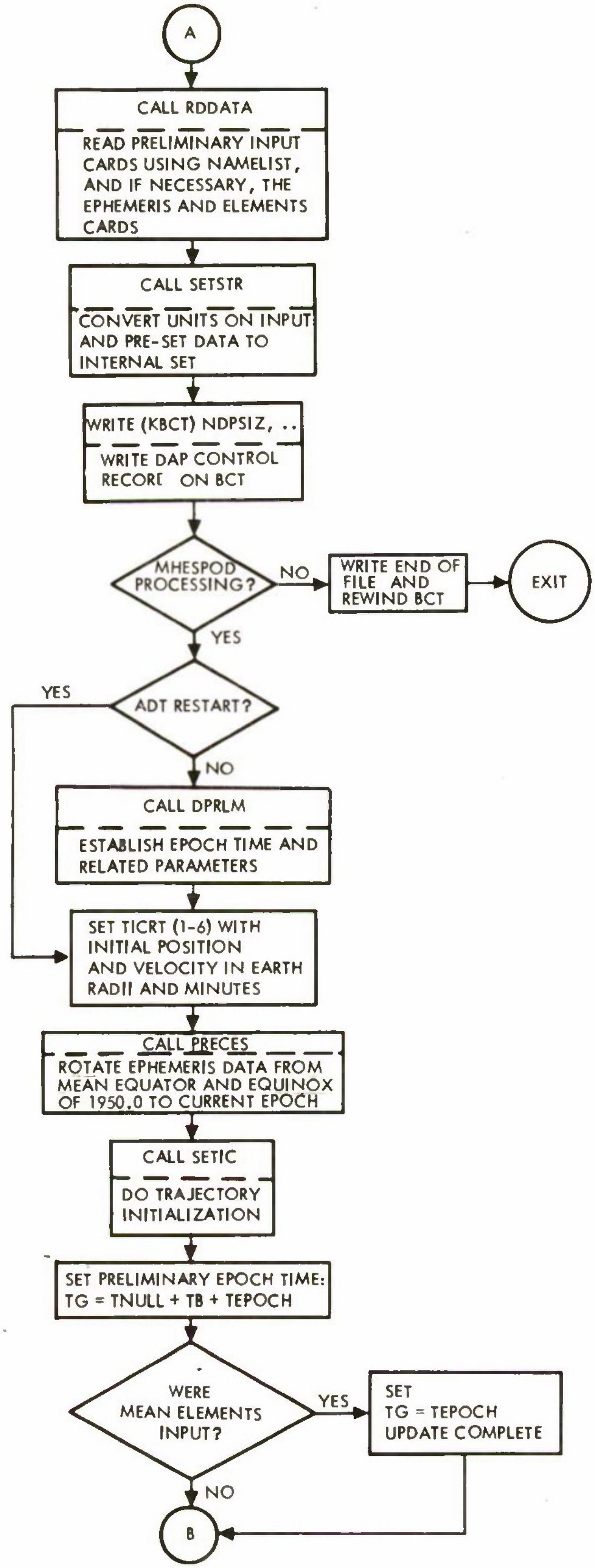


Figure 1-1. Functional Logic Flow of the PREMOD Program (Continued)

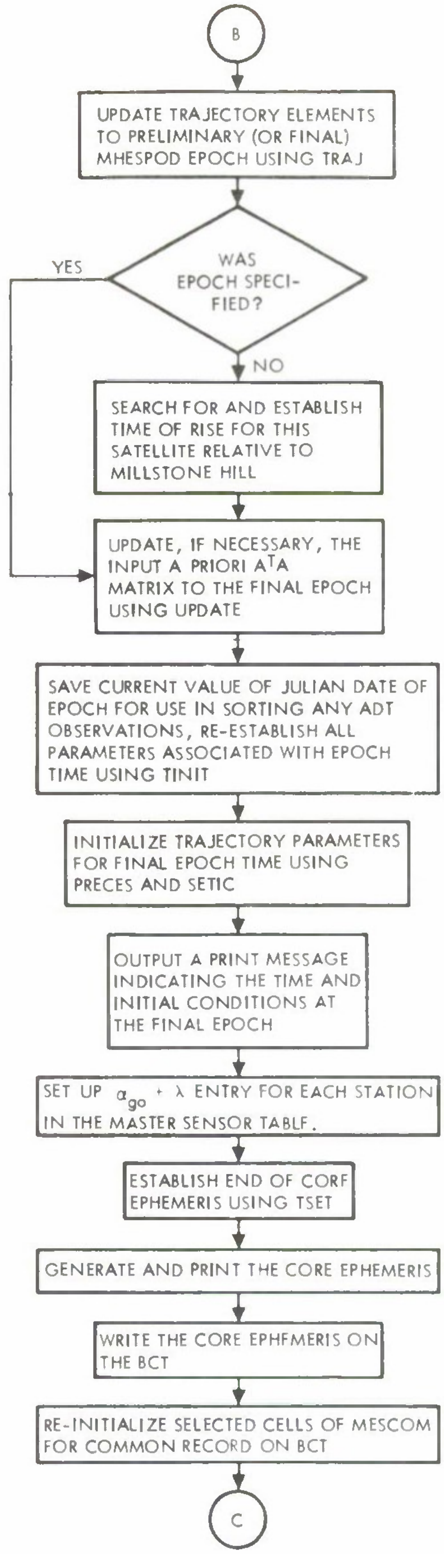


Figure 1-1. Functional Logic Flow of the PREMOD Program (Continued)

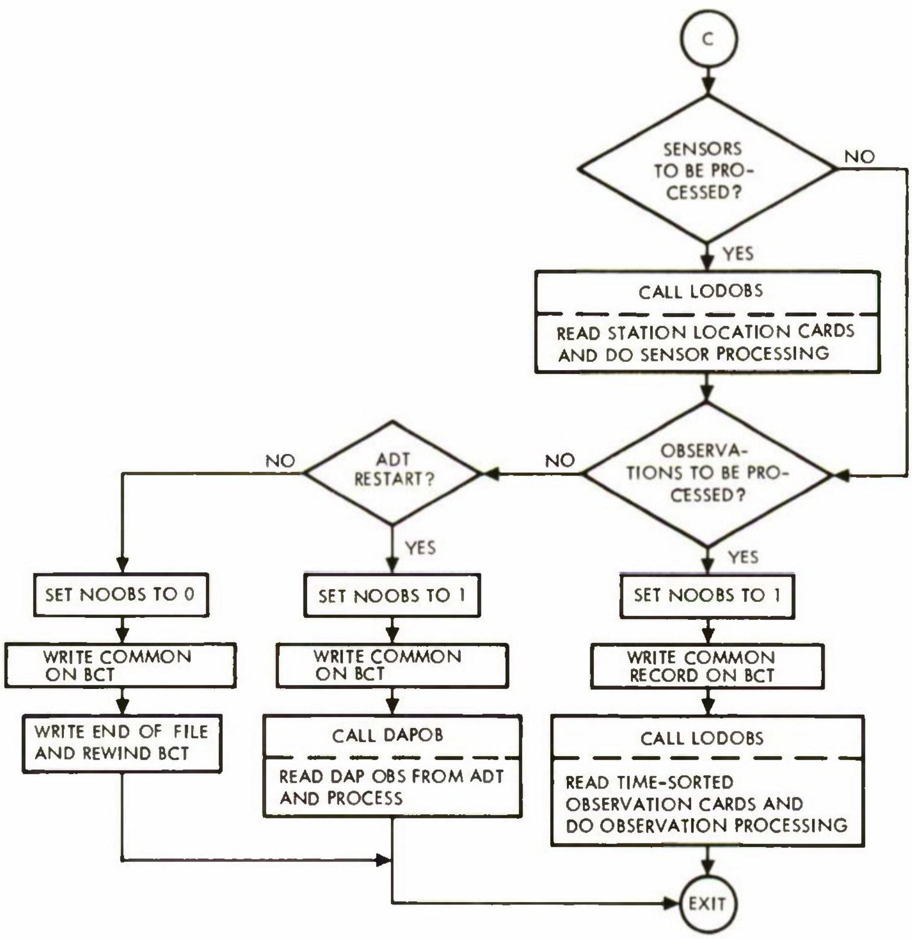


Figure 1-1. Functional Logic Flow of the PREMOD Program (Continued)

Figure 1-2 on the following page is a functional diagram in terms of the mathematical operations and sequences. It is primarily an analytical representation of the differential correction process with the general input/output processes added. Computer programing representations of this figure in terms of subroutines are given in Section 5.1.

1.2 INPUT

1.2.1 PREMOD-MHESPOD Input Deck Setup

The input deck always consists of at least two cards: (1) the JDC card and (2) the Remark Card. Other cards may have to be included, depending on the options which are called. The sequential order of the input deck is given below.

1. JDC Card
2. Remark Card

   if a BCT Tape is written,

3. Preliminary Data Cards

   if MHESPOD Processing
   if Type 3 Elements

4. Mean Elements
5. Ephemeris Cards
6. Sensor Cards, if any
7. End
8. Observation Cards, if any
9. End

1.2.2 JDC Card

The JDC (Job Description Card) is a mandatory input to all runs and is primarily used to identify the run and to call out the various options available to the analyst. A column-by-column description of the JDC follows.

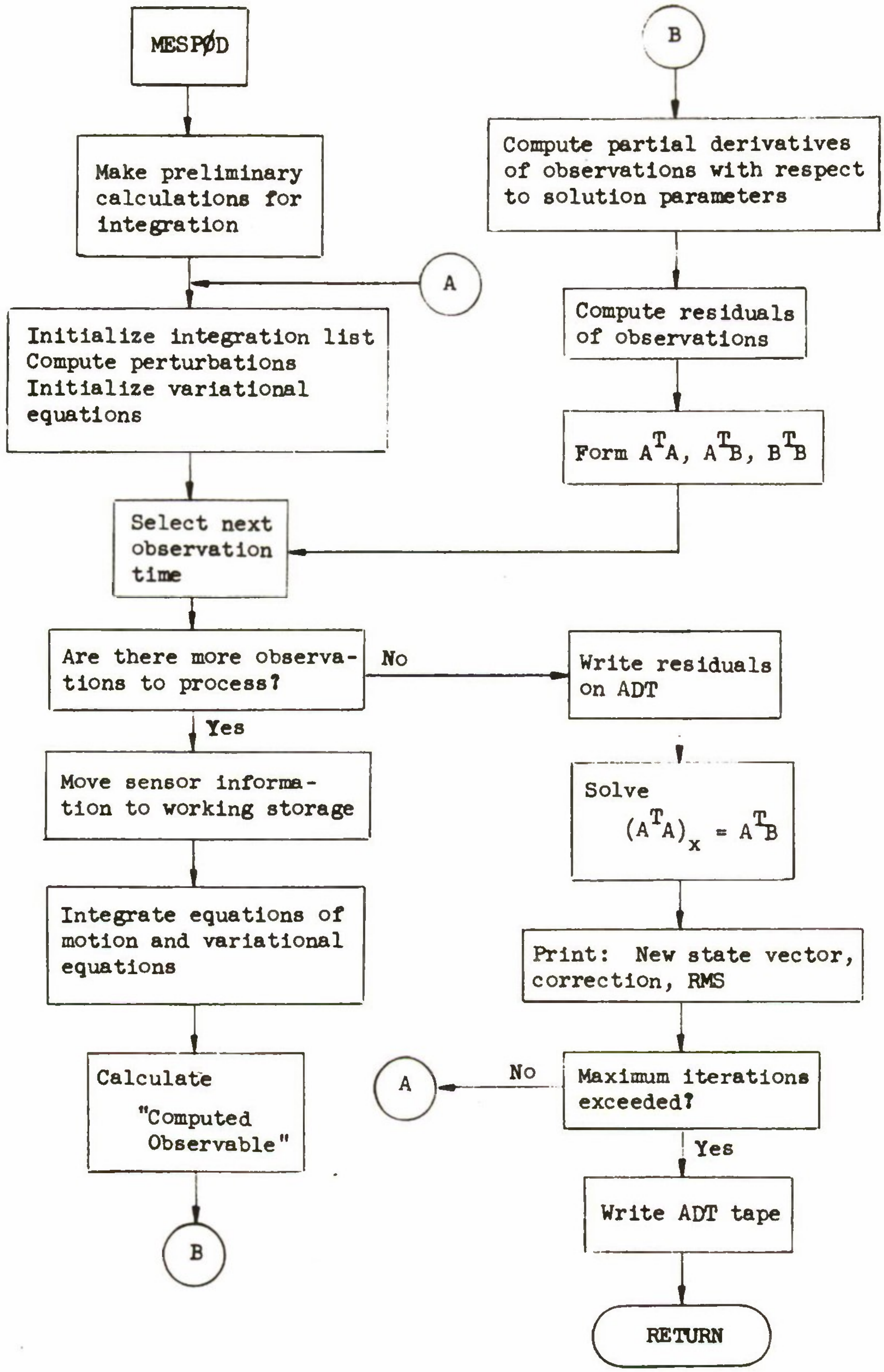


Figure 1-2. MHESPOD Functional Diagram

Column	Description
1-3	JDC
4	Blank
5-9	Vehicle number
10	Blank
11-12	Year - 1900
13-14	Month number
15-16	Day
17-18	Blank
19	$\neq 0$, print DAP tape
20	= 1, ADT print; = 2, ADT print plus core ephemeris print
21	$\neq 0$, ADT restart
22-24	Blank
25	$\neq 0$, generate BCT
26	$\neq 0$, record raw data by DAP
27-29	Blank
30	$\neq 0$, if MHESPOD processing
31	$\neq 0$, if sensors on cards
32	$\neq 0$, if observations on cards
33	$= 0$, $\dot{A}$, $\dot{E}$, $\ddot{R}$ $\neq 0$, $\partial R/\partial t$, $\partial A/\partial t$, $\partial E/\partial t$
34	$\neq 0$, record residuals on ADT
35	$\neq 0$, write core ephemeris on ADT

1.2.3 Remark Card

The Remark Card is always the second card in the input deck. It has no identifying characteristics ("REMARK" need not be punched in the first seven columns) except for its unique position in the input deck—it follows the JDC card.

All 72 columns are interpreted and printed on each run. Therefore, if the card is omitted, the card which follows the JDC card, presumably a preliminary data card, will be interpreted as a Remark Card and will result in subsequent input errors.

1.2.4 Preliminary Data Cards

The preliminary data cards are in the NAMELIST format. A few remarks concerning the use of NAMELIST as it applies to the IBM 7094 on which this program was developed are included here. Most of the conventions enumerated below apply equally well to the SDS 9300.

1. The first column of each card is always blank
2. The first data card contains: \$INPUT
   The last data card: \$
3. An equal sign follows each input name
4. Commas separate the individual entries of an input array
5. A comma is the last character on each card
6. Cards are free-form from columns 2 to 72; there may be any number of entries per card and a particular input name may go from card to card
7. Numbers may be expressed in decimal or in exponential floating point.

The various types of preliminary input cards are described on the following pages. In instances where a strict adherence to a particular format is indicated, such as sensor cards, a column-by-column description is given.

TYPE = single entry input specifying the coordinate system of the initial conditions

= 1 Geocentric Cartesian state vector

= 2 Geocentric polar (ADBARV) state vector

= 3 SPADATS/SPACETRACK mean elements

STVEC = Six-entry array specifying initial conditions

If TYPE = 1,

x, y, z Components of Cartesian position vector — kilometers

$\dot{x}, \dot{y}, \dot{z}$ Components of Cartesian velocity vector — kilometers/second

If TYPE = 2,

α	Right ascension of vehicle — degrees
δ	Declination of vehicle — degrees
β	Flight path angle — degrees
A	Azimuth of velocity vector — degrees
r	Geocentric range — kilometers
v	Magnitude of velocity vector — kilometers/second

If TYPE = 3,

Mean elements in the new SPADATS/SPACETRACK format are input. This is a six-card element set, the description of which follows.

CARD NO. 1

Columns 1 — Card Number (1)
2 — Space
3-7 — Satellite Number
8 — Space
9 — Classification
    "S" if secret
    "C" if confidential
    "U" if unclassified
10 — Space
11 — Source of Elements*
    e.g., Space if SPACETRACK
    9 if SPASUR
12-15 — Element Set Number
16 — Space
17-27 — International Name
    Cols 17-18 Last two digits of year
    19 Space
    20-23 Greek letter name of identifying number
    24 Space
    25-27 Piece number of alphabetic piece description
28 — Space
29-30 — Ephemeris type (numeric code)*
    e.g., 01 Aeronutronic Simplified General Perturbations w/Kozai semi-major axis
31 — Differential Correction (numeric code)*
32 — Atmosphere (numeric code)*
    e.g., 0 No atmosphere defined
    1 Lockheed - Jacchia
33 — Space

*Final values will be assigned at a future date.

CARD NO. 1 (Continued)

Columns 34	Accuracy (numeric code)*	
	e. g., 1 ±5.0 seconds	
35	Space	
36-39	Estimated Element Life from Epoch (up to 99.9 days) within specified accuracy	
	Cols 36-37	Integral part
	38	Decimal point
	39	Decimal fraction
40	Space	
41-46	Integral Revolutions from Launch at Epoch, N_O. Revolution number 1 commences at first ascending node. Decimal point implied between colums 46 and 47.	
47	Space	
48-51	Date of Epoch	
	Cols 48	Last digit of calendar year
	49-51	Day of year
52	Space	
53-59	Ballistic Coefficient, C_DA/m, meters squared per kilogram (floating point**)	
	Cols 53-57	Decimal fraction
	58	Sign of exponent
	59	Exponent of 10
60	Space	
61-67	Reflectivity Factor, $\gamma A/m$, meters squared per kilogram (floating point)	
	Cols 61-65	Decimal fraction
	66	Sign of exponent
	67	Exponent of 10
68	Space	
69	Check Sum. Arithmetic sum, modulo 10, of all numeric characters in line (Columns 1-68). Add 1 for minus signs, 2 for plus signs, 0 for spaces, decimal points and alphabetic characters.	
70-75	Internal Control Codes	
	e. g., ISTOP	
	CSTOP	
	BLTN Batching Indicator	
76-79	Element set number	
80	"E"	

*Final values will be assigned at a future date.

**Floating point numbers will be constructed as follows. The decimal fraction will be left justified, normalized and preceded by an implied decimal point. The sign of the exponent will be punched whether positive or negative. The plus sign (+) will be represented by the symbol " in teletype transmission. Provision will be made for exponent (of 10) fields requiring more than one digit by reducing the size of the decimal fraction field proportionately.

CARD NO. 2

Columns	1	Card Number (2)
	2	Space
	3-7	Satellite Number
	8	Space
	9-22	Epoch, T, Modified Julian Days (Julian Day minus 2,400,000.5) Cols 9-13 Integral part 14 Decimal point 15 Decimal fraction
	23	Space
	24-31	Mean Anomaly, M, degrees Cols 24-26 Integral part 27 Decimal point 28-31 Decimal fraction
	32	Space
	33-40	Right Ascension of the Ascending Node, Ω, degrees Cols 33-35 Integral part 36 Decimal point 37-40 Decimal fraction
	41	Space
	42-49	Argument of Perigee, ω, degrees Cols 42-44 Integral part 45 Decimal point 46-49 Decimal fraction
	50	Space
	51-58	Eccentricity, e (dimensionless) Cols 51 Decimal point 52-58 Decimal fraction
	59	Space
	60-67	Inclination, i, degrees Cols 60-62 Integral part 63 Decimal point 64-67 Decimal fraction
	68	Space
	69	Check Sum (as in Card No. 1)
	70-80	As in Card No. 1

Note: If integral part of epoch time in MJD is unspecified (blank), date of epoch on Card No. 1 will be used as source of this data.

CARD NO. 3

Columns	1	Card Number (3)
	2	Space
	3-7	Satellite Number
	8	Space
	9-19	Mean Motion (mean), n, revolutions/day Cols 9-10 Integral part 11 Decimal point 12-19 Decimal fraction

CARD NO. 3 (Continued)

Columns	20	Space
	21-31	First Time Derivative* of Mean Motion, $\dot{n}/2$, revolutions/day^2
		Cols 21 Sign**
		22 Decimal point
		23-31 Decimal fraction
	32	Space
	33-40	First Time Derivative of Right Ascension of Ascending Node, $\dot{\Omega}$, degrees/day
		Cols 33 Sign
		34 Integral part
		35 Decimal point
		36-40 Decimal fraction
	41	Space
	42-49	First Time Derivative of Argument of Perigee, $\dot{\omega}$, degrees/day
		Cols 42 Sign
		43 Integral part***
		44 Decimal point
		45-49 Decimal fraction
	50	Space
	51-58	First Time Derivative of Eccentricity, $\dot{e}$, /day (floating point)
		Cols 51 Sign
		52-56 Decimal fraction
		57 Sign of exponent
		58 Exponent of 10
	59	Space
	60-67	First Time Derivative of Inclination, $\dot{i}$, degrees/day (floating point)
		Cols 60 Sign
		61-65 Decimal fraction
		66 Sign of exponent
		67 Exponent of 10
	68	Space
	69	Check Sum (as in Card No. 1)
	70-80	As in Card No. 1

*Although actual quantity may be the product of the derivative and a numeric coefficient, it will be referred to simply as the derivative.

**Only minus signs will be punched (except as noted earlier for signed exponents of floating point numbers).

***The sign position will be pre-empted when positive values of $\dot{\omega}$ require two digits to express the integral part.

CARD NO. 4

Columns	1	Card Number (4)
	2	Space
	3-7	Satellite Number
	8	Space
	9-19	Second Time Derivative of Mean Motion, $\ddot{n}/6$, revolutions/days^3 (floating point) Cols 9 Sign 10-17 Decimal fraction 18 Sign of exponent 19 Exponent of 10
	20	Space
	21-31	Third Time Derivative of Mean Motion, $\dddot{n}/24$, revolutions/days^4 (floating point) Cols 21 Sign 22-29 Decimal fraction 30 Sign of exponent 31 Exponent of 10
	32	Space
	33-40	Second Time Derivative of Right Ascension of Ascending Node, $\ddot{\Omega}/2$, degrees/day^2 (floating point) Cols 33 Sign 34-38 Decimal fraction 39 Sign of exponent 40 Exponent of 10
	41	Space
	42-49	Second Time Derivative of Argument of Perigee, $\ddot{\omega}/2$, degrees/day^2 (floating point) Cols 42 Sign 43-47 Decimal fraction 48 Sign of exponent 49 Exponent of 10
	50	Space
	51-58	Second Time Derivative of Eccentricity, $\ddot{e}/2$, /day^2 (floating point) Cols 51 Sign 52-56 Decimal fraction 57 Sign of exponent 58 Exponent of 10
	59	Space
	60-67	Unused (spaces)
	68	Space
	69	Check Sum (as in Card No. 1)
	70-80	As in Card No. 1

CARD NO. 5

Columns	1	Card Number (5)
	2	Space
	3-7	Satellite Number
	8	Space

CARD NO. 5 (Continued)

Columns	9-19	Semi-major Axis, a, mean equatorial earth radii
		Cols 9-10 Integral part
		11 Decimal point
		12-19 Decimal fraction
	20	Space
	21-30	First Time Derivative of Semi-major Axis, $\dot{a}$, earth radii/day (floating point)
		Cols 21 Sign
		22-28 Decimal fraction
		29 Sign of exponent
		30 Exponent of 10
	31	Space
	32-41	Second Time Derivative of Semi-major Axis, $\ddot{a}/2$, earth radii/day^2 (floating point)
		Cols 32 Sign
		33-39 Decimal fraction
		40 Sign of exponent
		41 Exponent of 10
	42	Space
	43	Check Sum (as in Card No. 1)
	44-75	Unused
	76-80	As in Card No. 1

CARD NO. 6

Columns	1	Card Number (6)*
	2	Space
	3-7	Satellite Number
	8	Space
	9-18	Anomalistic Period, Pa, minutes/revolution (floating point)
		Cols 9-16 Decimal fraction
		17 Sign of exponent
		18 Exponent of 10
	19	Space
	20-27	Anomalistic Drag Term, Ca, days/revolution^2 (floating point)
		Cols 20 Sign
		21-25 Decimal fraction
		26 Sign of exponent
		27 Exponent of 10
	28	Space
	29-35	Height of Perigee Above the Reference Spheroid, Hp, kilometers. Decimal point implied between Columns 35 and 36.
	36	Space

*This card not intended for teletype transmission.

CARD NO. 6 (Continued)

Columns	37-42	Initial Revolution Number of (Bulletin) Prediction Elements, Ni. Decimal point implied between Columns 42 and 43.
	43	Space
	44-46	Number of Revolutions from Initial Revolution to Expiration of Prediction Elements, ΔN. Decimal point implied between Columns 46 and 47.
	47	Space
	48-54	Expiration Date of Prediction Elements Cols 48 Last digit of year 49-50 Month 51-52 Day 53-54 Hour
	55	Space
	56-65	Nodal Period, Pn, minutes/revolution (floating point) Cols 56-63 Decimal fraction 64 Sign of exponent 65 Exponent of 10
	66	Space
	67-74	Nodal Drag Term, Cn, days/revolution^2 (floating point) Cols 67 Sign 68-72 Decimal fraction 73 Sign of exponent 74 Exponent of 10
	75	Space
	76-80	As in Card No. 1

Note: If the mean motion terms in Card No. 3 are unspecified, Pa and Ca will be employed internally in their derivation.

TIME = Six-entry array or less specifying epoch time of input state vector (STVEC). This entry is omitted if TYPE = 3, mean elements.

Entries	
year	(year - 1900)
month	1 = January, 2 = February, etc.
day	day of month (may be fractional)
hour	may be fractional
minute	may be fractional
second	may be fractional

DRAG = Ballistic coefficient, if single entry.

	DRAG	$C_D A/m$ (meter^2/kg)
or	DRAGCD	C_D, drag coefficient, dimensionless
and	DRAGA	A, area of spacecraft, meter^2
and	DRAGM	M, mass of spacecraft, kilogram

RADPR = Reflectivity, if single entry.

	RADPR	$\gamma A/m$ (meter^2/kg)
or	RPGAM	γ, dimensionless
and	RPA	A, meter^2
and	RPM	m, kilogram

ZONAL = The ZONAL input flags the coefficients of the zonal harmonics which are to be included in the geopotential model. It is a 12 entry array, J_1 through J_{12}. If only the first five cells are flagged, the remaining are assumed zero. J_2, J_3, J_4 are nominally set. Examples follow.

1. To call J_2 through J_6 only:

   ZONAL = 0., 1., 1., 1., 1., 1.,

2. To call J_7, J_8, J_9

   ZONAL (2) = 0., 0., 0., 0., 0., 1., 1., 1.,

SECT

The SECT input flags the coefficients of the sectorial harmonics which are to be included in the geopotential model. It is a six-entry array, J_{11} through J_{66}. Unless pre-set to zero, J_{22} is always included.

TESS

The TESS input flags the coefficients of the tesseral harmonics which are to be included in the geopotential model. It is a 15-entry array as explained below. As in the ZONAL and SECT inputs, a "1" is entered for inclusion, a "0" to exclude. Nominally, all entries are pre-set to zero.

TESS Array

1	J_{21}	9	J_{53}
2	J_{31}	10	J_{54}
3	J_{32}	11	J_{61}
4	J_{41}	12	J_{62}
5	J_{42}	13	J_{63}
6	J_{43}	14	J_{64}
7	J_{51}	15	J_{65}
8	J_{52}		

NITER

The NITER input controls the number of iterations which MHESPOD will execute. Since there is no convergence criterion in MHESPOD, the program will always go NITER iterations. NITER is pre-set to one.

TNULL

The TNULL input specifies the time to which the input state vector is to be updated. The time is referenced to the epoch time, TIME.

TNULL = DAYS., MINUTES., SECONDS.,

or TNULL(2) = MINUTES., SECONDS.,

or TNULL(3) = SECONDS.,

TB

The TB input is the time to which the epoch time (TIME) is updated, and from which time a rise search is initiated. The input format is the same as TNULL, given above.

TF

The TF input specifies the time to which the core ephemeris is to be computed. The time TF is referenced to the time of rise if the TB option was used, or TNULL.

SMAT

The SMAT input is the a priori normal matrix. It is input as an upper triangular matrix (6 x 6) by rows. Hence there are 21 entries. The input units are in terms of kilometers and seconds.

Entry Number

(1-6)	→	a_{11}	a_{12}	a_{13}	a_{14}	a_{15}	a_{16}
(7-11)	→		a_{22}	a_{23}	a_{24}	a_{25}	a_{26}
(12-15)	→			a_{33}	a_{34}	a_{35}	a_{36}
(16-18)	→				a_{44}	a_{45}	a_{46}
(19-20)	→					a_{55}	a_{56}
(21)	→						a_{66}

COMPRE(XX)

This card input enables the analyst to change a value in PREMOD COMMON.

COMMES(XX)

This card input enables the analyst to change a value in MHESPOD COMMON.

The following Preliminary Card Inputs are specifically related to the DAP subroutine.

RCRIT

This is the range editor critical deviation. The nominal value is 16,500 meters.

VCRIT

This is the range rate editor critical deviation. The nominal value is 9 meters/second

TBIAS

Time bias in seconds.

RBIAS

Range bias in meters.

VBIAS

Range rate bias in meters/second.

EBIAS

Elevation bias in degrees.

ABIAS

Azimuth bias in degrees.

The following inputs are related to the LAP subroutine.

CSUBA

Azimuth servo-lag, nominally 0.05 degrees.

CSUBE

Elevation servo-lag, nominally 0.05 degrees.

CEP1

Integer which controls the range of core ephemeris intervals. Nominally, CEP1 = 60.

1.2.5 Sensor Cards

The sensor card formats to be used with the Lincoln Laboratory programs PREMOD and NRTPOD are defined below.

The sensor identification is three numerical digits entered in the first three columns. Two additional identifying columns are provided to permit biases to be different from pass to pass. The full identification parallels the format on the observation cards.

The type column indicates the type of information on the card according to the following key:

Type Number (column 7)

Kind of Data on Card	1 Locations	2 Biases	3 Standard Deviations
Field 4	Latitude	Azimuth Bias	σ_A
Field 5	Longitude	Elevation Bias	σ_E
Field 6	Height	Range Bias	σ_R
Field 7		$\dot{R}$ Bias	$\sigma_{\dot{R}}$
Field 8		$\ddot{R}$ Bias	$\sigma_{\ddot{R}}$
Field 9		Time Bias	

The data fields are each nine columns wide. Data may be input in any of the conventional FORTRAN arrangements, that is, with either implicit decimal point or punched decimal point, and with or without a right adjusted exponent of ten preceded by a punched plus or minus sign. If the first column of a field is not punched - (minus), the contained value is assumed positive. The implicit decimal point is located between the first and second column of each field. On the card implicit decimal points appear between the following pairs of columns: 9-10, 19-20, 29-30, 39-40, 49-50, and 59-60.

Field	Columns	Description
1	1-3	Station ID
2	4-5	Pass number: applicable to type 2 (biases) cards only
	6	Space = blank
3	7	Type
		Blank or 0: Error on input, disregarded
		1: Interpret ϕ, λ, h
		2: Interpret A_b, E_b, R_b, $\dot{R}_b$, $\ddot{R}_b$, t_b
		3: Interpret σ_A, σ_E, σ_R, $\sigma_{\dot{R}}$, $\sigma_{\ddot{R}}$
	8	Space = blank
4	9-17	Type 1: Geodetic latitude ϕ degrees (positive north)
		Type 2: Bias in Azimuth A_b degrees
		Type 3: σ_A degrees
	18	Space = blank
5	19-27	Type 1: Longitude λ degrees (positive east of Greenwich)
		Type 2: Bias in Elevation E_b degrees
		Type 3: σ_E degrees
	28	Space = blank
6	29-37	Type 1: Height h meters (positive above ellipsoid)
		Type 2: Bias in Range R_b km
		Type 3: σ_R km
	38	Space = blank

Field	Columns	Description
7	39-47	Type 1:
		Type 2: Bias in first time derivative of range $\dot{R}_b$ km/sec
		Type 3: $\sigma_{\dot{R}}$ km/sec
	48	Space = blank
8	49-57	Type 1:
		Type 2: Bias in second time derivative of range $\ddot{R}_b$ m/sec^2
		Type 3: $\sigma_{\ddot{R}}$ m/sec^2
	58	Space = blank
9	59-67	Type 1:
		Type 2: Bias in assigned time of observation t_b sec
		Type 3:
10	68-78	Not used, reserved for station name
11	79-80	Not used, to be punched with some unambiguous mnemonic to identify this card conveniently as a sensor card.

1.2.6 Observation Cards

The observation card format of the Lincoln Laboratory orbit determination programs PREMOD, MHESPOD, and NRTPOD is defined below.

The accuracies implied by the lengths of the fields are greater than sensors can currently measure. The time format is more accurate than the FORTRAN coding can accommodate. These provisions for extra accuracy have been made to allow for system improvements.

The time zone column has been abolished. This seldom used option can be replaced, for those cases where observations cannot be preprocessed to correct from local time to Greenwich time, by a supplementary code in the type column (26). This sets a flag to initiate a special reduction of time. This option has not been implemented into any of the Lincoln Laboratory orbit determination programs and is not contemplated at this time.

Estimated standard deviations of a particular observation may be entered on the observation card. The field for a standard deviation consists of three columns, and follows the field of the particular observable to which the standard deviation applies. The first two columns are interpreted as an integer x 10^{-5}. The third column is interpreted as a positive exponent of 10. The full range of values which may be represented (in the units of the observable) are:

$$10^{-5} \le \sigma \le 99 \times 10^{4}$$

Sample values are given below.

$$0.55 = 553$$
$$1 = 015$$

Fractions of angles <u>cannot</u> be inserted in units of minutes and seconds of arc. All fractions of angles must be expressed in decimal fractions of a degree.

A decimal point may be punched arbitrarily into any one position within a field where observables (A, E, $\dot{R}$, $\ddot{R}$, R, α, δ) appear. If the decimal point is not punched in any particular field, either by design or accidentally, the program assumes the following implicit locations for decimal points:

Field 5 (A, δ)	Implicit decimal point between columns 29 and 30
Field 7 (E, δ)	Implicit decimal point between columns 41 and 42
Field 9 (R, $\ddot{R}$)	Implicit decimal point between columns 62 and 63
Field 11 ($\dot{R}$)	Implicit decimal point between columns 70 and 71

Field	Columns	Description
1	1-3	Station ID
2	4-5	Pass number
	6	Space = blank
3	7-8	Year (= year - 1900)
	9-10	Month (January = 1)
	11-12	Day of calendar month
	13-14	Greenwich hour of day
	15-16	Minutes
	17-18	Integral seconds
	19	Decimal point
	20-25	Fractional seconds
4	26	Type
		Blank or 0: Interpret A E R $\dot{R}$ 1: Interpret $\ddot{R}$ 2: Interpret α δ 3-9: To be determined
5	27-34	Type 0: Azimuth; A, degrees (positive east of north)
		Type 1:
		Type 2: Right ascension; α, degrees (positive east of Greenwich)
6	35-37	Type 0: σ_A, degrees
		Type 1:
		Type 2: σ_α, degrees
	38	Space = blank
7	39-46	Type 0: Elevation; E, degrees
		Type 1:
		Type 2: Declination; δ, degrees

Field	Columns	Description
8	47-49	Type 0: σ_E, degrees
		Type 1:
		Type 2: σ_δ, degrees
	50	Space = blank
9	51-62	Type 0: Range; R, km
		Type 1: Range acceleration; $\ddot{R}$, m/sec^2
		Type 2:
10	63-65	Type 0: σ_R, km
		Type 1: $\sigma_{\ddot{R}}$, m/sec^2
		Type 2:
	66	Space = blank
11	67-75	Type 0: Range rate; $\dot{R}$, km/sec
		Type 1:
		Type 2:
12	76-78	Type 0: $\sigma_{\dot{R}}$, km/sec
		Type 1:
		Type 2:
13	79-80	Not used, to be punched with some unambiguous mnemonic to identify this card as an observation card

1.2.7 Ephemeris Cards

PREMOD-MHESPOD requires that 16 ephemeris cards, in a specific format describing the position and position differences of the moon and sun for 4 days, are included in the input deck. See Section 1.2.1 for the deck setup description. One day of lunar-solar ephemeris data is represented on the 4-card format description which follows.

JD_1 mod 2430000	x_{moon}	$\delta^2 x_{moon}$	$\delta^4 x_{moon}$	y_{moon}	M1	Card 1
Col. 1-14	Col. 15-28	Col. 29-42	Col. 43-56	Col. 57-70	Col. 73-80	

$\delta^2 y_{moon}$	$\delta^4 y_{moon}$	z_{moon}	$\delta^2 z_{moon}$	$\delta^4 z_{moon}$	M2	Card 2
Col. 1-14	Col. 15-28	Col. 29-42	Col. 43-56	Col. 57-70	Col. 73-80	

JD_1 mod 2430000	x_{sun}	$\delta^2 x_{sun}$	$\delta^4 x_{sun}$	y_{sun}	S1	Card 3
Col. 1-14	Col. 15-28	Col. 29-42	Col. 43-56	Col. 57-70	Col. 73-80	

$\delta^2 y_{sun}$	$\delta^4 y_{sun}$	z_{sun}	$\delta^2 z_{sun}$	$\delta^4 z_{sun}$	S2	Card 4

where

Card 1

JD_1 = Julian date Mod 2430000

${x_{moon}}_{JD_1}$ = x coordinate of the moon referenced to the earth at time, JD_1

$\delta^2 {x_{moon}}_{JD_1}$ = 2nd central difference of the x_{moon} coordinate at time, JD_1

$\delta^4 {x_{moon}}_{JD_1}$ = 4th central difference of the x_{moon} coordinate at time, JD_1

${y_{moon}}_{JD_1}$ = y coordinate of the moon referenced to the earth at time, JD_1

Card 2

$\delta^2 y_{moon_{JD_1}}$ = 2nd central difference of y_{moon} coordinate at time, JD_1

$\delta^4 y_{moon_{JD_1}}$ = 4th central difference of y_{moon} coordinate at time, JD_1

$z_{moon_{JD_1}}$ = z coordinate of the moon referenced to the earth at time, JD_1

$\delta^2 z_{moon_{JD_1}}$ = 2nd central difference of the z_{moon} coordinate at time, JD_1

$\delta^4 z_{moon_{JD_1}}$ = 4th central difference of the z_{moon} coordinate at time, JD_1

Cards 3 and 4 contain information similar to cards 1 and 2 with solar coordinates being described for the same Julian date, JD_1.

Card columns 73-80 on all the above pictured cards are used as identifying columns. BCD information, M1, M2, S1, S2 respectively, denotes the type of card, being either moon or sun cards.

1.3 PREMOD-MHESPOD OUTPUT

PREMOD-MHESPOD produces output in the form of on-line (real time) printout, magnetic tapes, and off-line printout. This section explains the format, the parameters produced, and is supplemented by samples to clarify the description.

There are four distinct types of printed output which are associated with the PREMOD-MHESPOD programs. They are:

1) PREMOD output
2) MHESPOD on-line
3) ADT Print
4) DAP Tape Print

1.3.1 PREMOD Output

A PREMOD run always precedes a MHESPOD run and is executed in non-real time. The printed output consists of (1) the preliminary input conditions, (2) the final initial conditions, (3) the nominal core ephemeris, (4) tracking station data, and (5) the observations and standard deviations input on cards.

```
PRELIMINARY INITIAL CONDITIONS AT TNULL

                         ALPHA G ZERO
                         9.5148052E 00

              YEAR  MONTH  DAY  HOUR  MINUTE  SECOND
               65    10     1    0     59    59.999399

     X(KM)            Y(KM)           Z(KM)         XDOT(KM/SEC)     YDOT(KM/SEC)     ZDOT(KM/SEC)
-5.0330735E 02  -5.2423629E 03   1.1554443E 04   4.8825303E-01    5.0843475E 00    2.3007552E 00

   ALPHA(DEG)       DELTA(DEG)      BETA (DEG)       AZ (DEG)          R(KM)          V(KM/SEC)
 2.6451597E 02   6.5496692E 01   9.0254356E 01   1.1848689E-03    1.2698064E 04    5.6020045E 00
```

Figure 1-3. Sample Input Initial Conditions Header

FINAL INITIAL CONDITIONS AT TNULL

ALPHA G ZERO
5.5148052E 00

YEAR	MONTH	DAY	HOUR	MINUTE	SECOND
65	10	1	0	59	59.999399

X(KM)	Y(KM)	Z(KM)	XDOT(KM/SEC)	YDOT(KM/SEC)	ZDOT(KM/SEC)
-5.0330735E 02	-5.2423629E 03	1.1554443E 04	4.8825303E-01	5.0843474E 00	2.3007551E 00

ALPHA(DEG)	DELTA(DEG)	BETA (DEG)	AZ (DEG)	R(KM)	V(KM/SEC)
2.6451597E 02	6.5496692E 01	9.0254356E 01	1.1849282E-03	1.2698064E 04	5.6020044E 00

Figure 1-4. Sample Updated Initial Conditions Header

***** NOMINAL CORE EPHEMERIS *****

T(MIN)	RDOT(KM/SEC)	RANGE(KM)	AZ(DEG)	E(DEG)	DR/DT(KM/SEC)	DA/DT(DEG/SEC)	DE/DT(DEG/SEC)
59.99999	8.4390399E-01	8.3507138E 03	327.363407	28.7812605	6.8186794E-01	2.2719889E-02	-9.8530941E-03
60.54999	8.8154300E-01	8.3791854E 03	328.714161	28.3741629	7.2491118E-01	2.2983152E-02	-1.0372129E-02
61.09999	9.1851602E-01	8.4088882E 03	330.047249	27.9533603	7.6732996E-01	2.3239956E-02	-1.0870878E-02
61.64999	9.5480557E-01	8.4398000E 03	331.362514	27.5195072	8.0910653E-01	2.3489936E-02	-1.1349324E-02
62.19999	9.9041212E-01	8.4718982E 03	332.659870	27.0732532	8.5022525E-01	2.3732778E-02	-1.1807535E-02
62.74999	1.0253127E 00	8.5051595E 03	333.939262	26.6152408	8.9067115E-01	2.3968217E-02	-1.2245641E-02
63.29999	1.0595022E 00	8.5395610E 03	335.200706	26.1461029	9.3043106E-01	2.4196037E-02	-1.2663842E-02
63.84999	1.0929722E 00	8.5750787E 03	336.444237	25.6664603	9.6949277E-01	2.4416061E-02	-1.3062397E-02
64.39999	1.1257158E 00	8.6116891E 03	337.669945	25.1769223	1.0078455E 00	2.4628160E-02	-1.3441614E-02
64.94999	1.1577273E 00	8.6493680E 03	338.877956	24.6780808	1.0454798E 00	2.4832238E-02	-1.3801850E-02
65.49999	1.1890017E 00	8.6880910E 03	340.068424	24.1705158	1.0823872E 00	2.5028238E-02	-1.4143501E-02
66.04999	1.2195355E 00	8.7278340E 03	341.241539	23.6547914	1.1185605E 00	2.5216132E-02	-1.4466998E-02
66.59999	1.2493260E 00	8.7685722E 03	342.397503	23.1314528	1.1539937E 00	2.5395921E-02	-1.4772800E-02
67.14999	1.2783716E 00	8.8102813E 03	343.536556	22.6010313	1.1886818E 00	2.5567634E-02	-1.5061393E-02
67.69999	1.3066715E 00	8.8529366E 03	344.658958	22.0640342	1.2226211E 00	2.5731320E-02	-1.5333281E-02
68.24999	1.3342261E 00	8.8965136E 03	345.764980	21.5209568	1.2558085E 00	2.5887050E-02	-1.5588984E-02
68.79999	1.3610362E 00	8.9409872E 03	346.854919	20.9722736	1.2882421E 00	2.6034916E-02	-1.5829033E-02
69.34999	1.3871039E 00	8.9863336E 03	347.929073	20.4184396	1.3199210E 00	2.6175019E-02	-1.6053966E-02
69.89999	1.4124315E 00	9.0325279E 03	348.987762	19.8598955	1.3508449E 00	2.6307479E-02	-1.6264327E-02
70.44999	1.4370227E 00	9.0795460E 03	350.031311	19.2970564	1.3810147E 00	2.6432422E-02	-1.6460661E-02
70.99999	1.4608812E 00	9.1273633E 03	351.060047	18.7303264	1.4104317E 00	2.6549587E-02	-1.6643510E-02
71.54999	1.4840118E 00	9.1759561E 03	352.074318	18.1600876	1.4390982E 00	2.6660320E-02	-1.6813416E-02
72.09999	1.5064196E 00	9.2253003E 03	353.074455	17.5867074	1.4670170E 00	2.6763571E-02	-1.6970911E-02
72.64999	1.5281104E 00	9.2753719E 03	354.060810	17.0105338	1.4941918E 00	2.6859896E-02	-1.7116524E-02
73.19999	1.5490904E 00	9.3261477E 03	355.033726	16.4318974	1.5206266E 00	2.6949455E-02	-1.7250771E-02
73.74999	1.5693663E 00	9.3776041E 03	355.993553	15.8511144	1.5463262E 00	2.7032406E-02	-1.7374159E-02
74.29999	1.5889453E 00	9.4297183E 03	356.940639	15.2684839	1.5712957E 00	2.7108915E-02	-1.7487185E-02
74.84999	1.6078348E 00	9.4824671E 03	357.875324	14.6842837	1.5955410E 00	2.7179143E-02	-1.7590331E-02
75.39999	1.6260426E 00	9.5358279E 03	358.797958	14.0988017	1.6190680E 00	2.7243250E-02	-1.7684066E-02
75.94999	1.6435768E 00	9.5897783E 03	359.708874	13.5122725	1.6418833E 00	2.7301399E-02	-1.7768850E-02
76.49999	1.6604463E 00	9.6442966E 03	0.608418	12.9249431	1.6639941E 00	2.7353749E-02	-1.7845120E-02
77.04999	1.6766590E 00	9.6993607E 03	1.496909	12.3370415	1.6854073E 00	2.7400456E-02	-1.7913306E-02
77.59999	1.6922244E 00	9.7549490E 03	2.374681	11.7487805	1.7061304E 00	2.7441675E-02	-1.7973819E-02
78.14999	1.7071510E 00	9.8110403E 03	3.242056	11.1603639	1.7261712E 00	2.7477556E-02	-1.8027057E-02
78.69999	1.7214485E 00	9.8676138E 03	4.099354	10.5719786	1.7455380E 00	2.7508249E-02	-1.8073402E-02
79.24999	1.7351261E 00	9.9246489E 03	4.946885	9.9838051	1.7642388E 00	2.7533898E-02	-1.8113221E-02
79.79999	1.7481931E 00	9.9821258E 03	5.784956	9.3960115	1.7822820E 00	2.7554643E-02	-1.8146866E-02
80.34999	1.7606592E 00	1.0040023E 04	6.613866	8.8087540	1.7996763E 00	2.7570623E-02	-1.8174676E-02

Figure 1-5. Sample Nominal Core Ephemeris (PREMOD)

80.89999	1.7725340E 00	1.0098322E 04	7.433913	8.2221806	1.8164304E 00	2.7581970E-02	-1.8196974E-02
81.44999	1.7838270E 00	1.0157004E 04	8.245383	7.6364291	1.8325529E 00	2.7588816E-02	-1.8214068E-02
81.99999	1.7945483E 00	1.0216049E 04	9.048558	7.0516283	1.8480531E 00	2.7591286E-02	-1.8226255E-02
82.54999	1.8047072E 00	1.0275438E 04	9.843714	6.4678982	1.8629397E 00	2.7589502E-02	-1.8233814E-02
83.09999	1.8143137E 00	1.0335153E 04	10.631121	5.8853546	1.8772217E 00	2.7583582E-02	-1.8237018E-02
83.64999	1.8233771E 00	1.0395177E 04	11.411044	5.3040989	1.8909083E 00	2.7573641E-02	-1.8236118E-02
84.19999	1.8319073E 00	1.0455490E 04	12.183738	4.7242293	1.9040084E 00	2.7559792E-02	-1.8231363E-02
84.74999	1.8399137E 00	1.0516077E 04	12.949457	4.1458387	1.9165311E 00	2.7542138E-02	-1.8222980E-02
85.29999	1.8474062E 00	1.0576919E 04	13.708444	3.5690101	1.9284856E 00	2.7520787E-02	-1.8211193E-02
85.84999	1.8543938E 00	1.0638000E 04	14.460938	2.9938229	1.9398809E 00	2.7495836E-02	-1.8196208E-02
86.39999	1.8608866E 00	1.0699304E 04	15.207175	2.4203482	1.9507261E 00	2.7467383E-02	-1.8178221E-02
86.94999	1.8668933E 00	1.0760813E 04	15.947383	1.8486525	1.9610300E 00	2.7435523E-02	-1.8157426E-02
87.49999	1.8724235E 00	1.0822513E 04	16.681781	1.2787991	1.9708015E 00	2.7400347E-02	-1.8133996E-02
88.04999	1.8774859E 00	1.0884388E 04	17.410588	0.7108445	1.9800495E 00	2.7361941E-02	-1.8108103E-02
88.59999	1.8820900E 00	1.0946422E 04	18.134013	0.1448426	1.9887828E 00	2.7320390E-02	-1.8079904E-02
89.14999	1.8862444E 00	1.1008601E 04	18.852265	-0.4191613	1.9970100E 00	2.7275777E-02	-1.8049550E-02
89.69999	1.8899582E 00	1.1070910E 04	19.565543	-0.9811218	2.0047398E 00	2.7228182E-02	-1.8017184E-02
90.24999	1.8932401E 00	1.1133334E 04	20.274043	-1.5409983	2.0119808E 00	2.7177680E-02	-1.7982938E-02
90.79999	1.8960985E 00	1.1195859E 04	20.977957	-2.0987542	2.0187414E 00	2.7124347E-02	-1.7946941E-02
91.34999	1.8985419E 00	1.1258471E 04	21.677467	-2.6543547	2.0250297E 00	2.7068256E-02	-1.7909312E-02
91.89999	1.9005788E 00	1.1321158E 04	22.372760	-3.2077724	2.0308544E 00	2.7009478E-02	-1.7870163E-02
92.44999	1.9022169E 00	1.1383905E 04	23.064011	-3.7589768	2.0362229E 00	2.6948078E-02	-1.7829600E-02

TRACKING STATION DATA

ID	LATITUDE DEG	LONGITUDE DEG	HEIGHT METERS	RANGE BIAS KM	AZ BIAS DEG	EL BIAS DEG	RDOT BIAS KM/SEC
KW	9.39880	167.48300	25.	0.	0.	0.	0.
HH	42.62320	288.51130	145.	0.	0.	0.	0.
MH	42.61730	288.50859	156.	0.	0.	0.	0.

Figure 1-6. Sample Tracking Station Data Output (PREMOD)

OBSERVATIONS ON CARDS

ID	T(MIN)	RANGE(KM)	SIGMA	AZ(DEG)	SIGMA	E(DEG)	SIGMA	RDOT(KM/SEC)	SIGMA
MH	31.00000	8.8761301E 03	3.0E-03	251.95130	10.0E-03	22.248100	10.0E-03	-1.4078500E 00	3.0E-05
HH	31.00000	8.8765175E 03	3.0E-03	251.94730	10.0E-03	22.243500	10.0E-03	-1.4081920E 00	3.0E-05
MH	30.00000	8.9624380E 03	3.0E-03	249.98400	10.0E-03	21.199300	10.0E-03	-1.4686720E 00	3.0E-05
MH	30.00000	8.9628448E 03	3.0E-03	249.98030	10.0E-03	21.194500	10.0E-03	-1.4690000E 00	3.0E-05
MH	29.00000	9.0523243E 03	3.0E-03	248.07840	10.0E-03	20.126900	10.0E-03	-1.5271620E 00	3.0E-05
HH	29.00000	9.0527511E 03	3.0E-03	248.07490	10.0E-03	20.121900	10.0E-03	-1.5274770E 00	3.0E-05
MH	28.00000	9.1456501E 03	3.0E-03	246.23270	10.0E-03	19.033700	10.0E-03	-1.5832930E 00	3.0E-05
HH	28.00000	9.1460947E 03	3.0E-03	246.22950	10.0E-03	19.028600	10.0E-03	-1.5835940E 00	3.0E-05
MH	27.00000	9.2422717E 03	3.0E-03	244.44510	10.0E-03	17.922500	10.0E-03	-1.6370510E 00	3.0E-05
HH	27.00000	9.2427347E 03	3.0E-03	244.44230	10.0E-03	17.917300	10.0E-03	-1.6373370E 00	3.0E-05
MH	26.00000	9.3420480E 03	3.0E-03	242.71390	10.0E-03	16.795700	10.0E-03	-1.6884280E 00	3.0E-05
HH	26.00000	9.3425276E 03	3.0E-03	242.71130	10.0E-03	16.790500	10.0E-03	-1.6887000E 00	3.0E-05
MH	25.00000	9.4448354E 03	3.0E-03	241.03670	10.0E-03	15.655800	10.0E-03	-1.7374250E 00	3.0E-05
HH	25.00000	9.4453310E 03	3.0E-03	241.03440	10.0E-03	15.650400	10.0E-03	-1.7376820E 00	3.0E-05
MH	24.00000	9.5504918E 03	3.0E-03	239.41180	10.0E-03	14.504800	10.0E-03	-1.7840510E 00	3.0E-05
HH	24.00000	9.5510021E 03	3.0E-03	239.40970	10.0E-03	14.499400	10.0E-03	-1.7842960E 00	3.0E-05
MH	23.00000	9.6588752E 03	3.0E-03	237.83690	10.0E-03	13.344700	10.0E-03	-1.8283240E 00	3.0E-05
HH	23.00000	9.6593994E 03	3.0E-03	237.83510	10.0E-03	13.339200	10.0E-03	-1.8285540E 00	3.0E-05
MH	22.00000	9.7698442E 03	3.0E-03	236.31010	10.0E-03	12.177200	10.0E-03	-1.8702630E 00	3.0E-05
HH	22.00000	9.7703818E 03	3.0E-03	236.30860	10.0E-03	12.171700	10.0E-03	-1.8704800E 00	3.0E-05
MH	21.00000	9.8832606E 03	3.0E-03	234.82940	10.0E-03	11.003900	10.0E-03	-1.9098980E 00	3.0E-05
HH	21.00000	9.8838109E 03	3.0E-03	234.82810	10.0E-03	10.998300	10.0E-03	-1.9101010E 00	3.0E-05
MH	20.00000	9.9989866E 03	3.0E-03	233.39260	10.0E-03	9.826300	10.0E-03	-1.9472570E 00	3.0E-05
HH	20.00000	9.9995482E 03	3.0E-03	233.39150	10.0E-03	9.820700	10.0E-03	-1.9474470E 00	3.0E-05
MH	19.00000	1.0116886E 04	3.0E-03	231.99790	10.0E-03	8.645700	10.0E-03	-1.9823780E 00	3.0E-05
HH	19.00000	1.0117460E 04	3.0E-03	231.99700	10.0E-03	8.640000	10.0E-03	-1.9825540E 00	3.0E-05
MH	18.00000	1.0236828E 04	3.0E-03	230.64340	10.0E-03	7.463100	10.0E-03	-2.0152970E 00	3.0E-05
HH	18.00000	1.0237411E 04	3.0E-03	230.64270	10.0E-03	7.457500	10.0E-03	-2.0154600E 00	3.0E-05
MH	17.00000	1.0358679E 04	3.0E-03	229.32730	10.0E-03	6.279700	10.0E-03	-2.0460560E 00	3.0E-05
HH	17.00000	1.0359272E 04	3.0E-03	229.32680	10.0E-03	6.274000	10.0E-03	-2.0462070E 00	3.0E-05
MH	16.00000	1.0482312E 04	3.0E-03	228.04770	10.0E-03	5.096300	10.0E-03	-2.0746970E 00	3.0E-05
HH	16.00000	1.0482914E 04	3.0E-03	228.04740	10.0E-03	5.090700	10.0E-03	-2.0748350E 00	3.0E-05
MH	15.00000	1.0607601E 04	3.0E-03	226.80290	10.0E-03	3.913800	10.0E-03	-2.1012640E 00	3.0E-05
HH	15.00000	1.0608210E 04	3.0E-03	226.80280	10.0E-03	3.908100	10.0E-03	-2.1013910E 00	3.0E-05
MH	14.00000	1.0734423E 04	3.0E-03	225.59140	10.0E-03	2.732800	10.0E-03	-2.1258030E 00	3.0E-05
HH	14.00000	1.0735040E 04	3.0E-03	225.59150	10.0E-03	2.727100	10.0E-03	-2.1259180E 00	3.0E-05
MH	13.00000	1.0862658E 04	3.0E-03	224.41160	10.0E-03	1.553900	10.0E-03	-2.1483600E 00	3.0E-05
HH	13.00000	1.0863281E 04	3.0E-03	224.41180	10.0E-03	1.548300	10.0E-03	-2.1484640E 00	3.0E-05
MH	12.00000	1.0992187E 04	3.0E-03	223.26200	10.0E-03	0.377800	10.0E-03	-2.1689810E 00	3.0E-05

Figure 1-7. Sample Observations on Cards Print (PREMOD)

```
EXECUTION
 CT          -0      (PREMOD-MHESPOD)  VS   (NRTPOD)

 ITERATION NUMBER  1
 VARIABLES        DELTA              NEW

          X    0.73901002E 00  -0.50256834E 03
          Y    0.21191262E-00  -0.52421509E 04
          Z   -0.31474821E-01   0.11554411E 05
       XDOT    0.23638653E-04   0.48827667E-00
       YDOT    0.10741261E-03   0.50844547E 01
       ZDOT   -0.20275640E-04   0.23007348E 01
     CURRENT RMS     81.776122

   PREDICTED RMS      0.054127
   TOTAL OBS               80.
   DAP ENTRIES              20


 ITERATION NUMBER  2
 VARIABLES        DELTA              NEW

          X   -0.11327199E 01  -0.50370105E 03
          Y   -0.12991951E 01  -0.52434500E 04
          Z   -0.55705091E 00   0.11553854E 05
       XDOT   -0.91164885E-04   0.48818550E-00
       YDOT   -0.28981945E-03   0.50841649E 01
       ZDOT    0.50678584E-03   0.23012416E 01
     CURRENT RMS     91.732977

   PREDICTED RMS      0.155414
   TOTAL OBS              240.
   DAP ENTRIES              20
```

Figure 1-8. Sample On-Line Output (MHESPOD)

The first page of output consists of the card images of the preliminary data input deck. The following page consists of the input preliminary conditions at TNULL (the time at which the rise search is initiated) in Cartesian and polar coordinates. See Figure 1-3. The next page gives the initial conditions and associated time which have been updated (to vehicle rise) in the same coordinate systems. See Figure 1-4.

This is followed by the nominal core ephemeris which is a predicted radar steering history of the vehicle for the Millstone Hill sensor. The ephemeris contains 60 equally spaced entries of time, range, azimuth, elevation, range rate, and either:

$$\frac{\partial R}{\partial t_o}, \quad \frac{\partial A}{\partial t_o}, \quad \frac{\partial E}{\partial t_o} \tag{1}$$

or

$$\ddot{R}, \ \dot{A}, \ \dot{E} \tag{2}$$

The time is in minutes and referenced from midnight of day of epoch, and the output units are kilometers, seconds, and degrees. The nominal core ephemeris is shown in Figure 1-5. Immediately following the core ephemeris is a tabulation of tracking station data. This consists of the station ID, geodetic latitude, longitude, height, and the observational biases to be applied to the data, if any. This is illustrated in Figure 1-6. The final item in the PREMOD output is a listing of the observations which were entered on cards. The standard deviations associated with each observation; whether entered on sensor cards or on the observation cards, are also printed. The time is referenced to epoch time. See Figure 1-7.

1.3.2 On-Line Output (MHESPOD)

The real time output of MHESPOD is an abbreviated version of the off-line output, allowing fast running time from iteration to iteration. The format of the on-line print is explained below and illustrated in Figure 1-8.

1) Iteration number

2)

Solution Variables	Correction	New State Vector	Units
X	ΔX	X	km
Y	ΔY	Y	km
Z	ΔZ	Z	km
$\dot{X}$	$\Delta \dot{X}$	$\dot{X}$	km/sec
$\dot{Y}$	$\Delta \dot{Y}$	$\dot{Y}$	km/sec
$\dot{Z}$	$\Delta \dot{Z}$	$\dot{Z}$	km/sec

3) Current RMS—Root mean square of weighted residuals-dimensionless

4) Predicted RMS

5) Total Observables - An observable is defined as a particular measurement, such as azimuth, at a particular time.

6) DAP Entries - A DAP entry is defined as a set of observables with a common time tag; e.g., R, A, E at time t.

1.3.3 ADT Print

PREMOD can be used as an output post-processor. In this capacity, PREMOD is used to print the ADT tape which was generated during a MHESPOD run. The output consists of: (1) the residuals by iteration, (2) the iteration summary, (3) the DAP observations on the ADT tape, if any, and (4) the ADT core ephemeris.

The residuals print is a chronological listing of the computed residuals. The time is referenced to the input epoch time as the observations in the PREMOD output. See Figure 1-9. As an analyst's output, the geocentric declination, the earth longitude, and a time residual are given on the residuals page. The definition of the time residual is: $DT = \Delta R/\dot{R}$.

The iteration summary immediately follows the residuals print and shows the results of applying the computed corrections. The first line identifies the iteration number. The following describes the tabulated solution vector date arranged in columns in the order shown below:

1) VARIABLE (X, Y, Z, $\dot{X}$, $\dot{Y}$, $\dot{Z}$)

2) DELTA The corrections applied to each variable

***** ADT PRINT *****

TAPE ID= ADT   TARGET ID=   -0   (PREMOD-MHESPOD) VS (NRTPOD)

RESIDUALS PRINT

ID	T(MIN)	RANGE(KM)	AZ(DEG)	EL(DEG)	RDOT(KM/SEC)	DECL(DEG)	LONG(DEG)	HT(METERS)	DT(SEC)
KW	226.00000	0.55733	0.00414	-0.00517	-0.000038	-42.184633	198.34509	0.	-0.228
KW	227.00000	0.55457	0.00425	-0.00523	-0.000048	-40.681052	198.09442	0.	-0.227
KW	228.00000	0.55219	0.00439	-0.00522	-0.000057	-39.177551	197.84375	0.	-0.227
KW	229.00000	0.54849	0.00450	-0.00533	-0.000066	-37.674119	197.59308	0.	-0.226
KW	230.00000	0.54421	0.00457	-0.00537	-0.000077	-36.170750	197.34241	0.	-0.225
KW	231.00000	0.53946	0.00476	-0.00542	-0.000087	-34.667433	197.09174	0.	-0.225
KW	232.00000	0.53404	0.00485	-0.00539	-0.000098	-33.164160	196.84106	0.	-0.224
KW	233.00000	0.52710	0.00499	-0.00549	-0.000109	-31.660922	196.59039	0.	-0.223
KW	234.00000	0.52026	0.00522	-0.00554	-0.000121	-30.157710	196.33972	0.	-0.222
KW	235.00000	0.51266	0.00541	-0.00553	-0.000134	-28.654516	196.08904	0.	-0.221
KW	236.00000	0.50420	0.00563	-0.00553	-0.000147	-27.151330	195.83837	0.	-0.220
KW	237.00000	0.49479	0.00579	-0.00561	-0.000161	-25.648144	195.58769	0.	-0.219
KW	238.00000	0.48462	0.00602	-0.00564	-0.000175	-24.144949	195.33702	0.	-0.218
KW	239.00000	0.47397	0.00628	-0.00566	-0.000190	-22.641736	195.08634	0.	-0.217
KW	240.00000	0.46209	0.00653	-0.00563	-0.000204	-21.138496	194.83566	0.	-0.216
KW	241.00000	0.44936	0.00692	-0.00559	-0.000220	-19.635220	194.58499	0.	-0.214
KW	242.00000	0.43567	0.00716	-0.00559	-0.000236	-18.131901	194.33431	0.	-0.213
KW	243.00000	0.42123	0.00753	-0.00557	-0.000252	-16.628527	194.08363	0.	-0.212
KW	244.00000	0.40554	0.00794	-0.00557	-0.000269	-15.125092	193.83296	0.	-0.210
KW	245.00000	0.33882	0.00839	-0.00544	-0.000286	-13.621588	193.58228	0.	-0.208

Figure 1-9. Sample Residuals Output, ADT Print

3) OLD — Numerical values for the variables from the previous iteration

4) NEW — Numerical values for the variables for this iteration (NEW = OLD + DELTA)

5) SIGMA — The uncertainty in each variable computed from the covariance matrix

In addition to the solution vector data described above, the new variables are also output in terms of the mean elements. The definition of mean elements follows:

A	Semi-major axis (earth-radii)
E	Eccentricity
I	Inclination (degrees)
NODE	Right ascension of ascending node (degrees)
OM	Argument of perigee (degrees)
M	Mean anomaly (degrees)

In addition, the first order (J_2) rates of change of the right ascension of the ascending node (NDOT) and the argument of perigee (ODOT) are given in units of degrees/day.

The total number of observations and the number of DAP entries is printed on this page. A DAP entry is defined as one radar point, hence, it may consist of up to four observables.

The current RMS (root mean square of weighted residuals) and the predicted RMS appear on the iteration summary. Finally, the normal matrix (A^TA) and the variance-covariance matrix (A^TA inverse) are printed on the iteration summary page. See Figure 1-10. Following the last iteration summary (the iteration maximum is specified by card input, NITER),a listing of the DAP observations on the ADT tape, if any, is given. The time is referenced to midnight of day and epoch; the standard deviations associated with the observations is also given. See Figure 1-11.

ITERATION NUMBER 2

VARIABLE	DELTA	OLD	NEW	SIGMA
X	-1.1327199E 00	-5.0256833E 02	-5.0370106E 02	2.0632398E-01
Y	-1.2991951E 00	-5.2421508E 03	-5.2434500E 03	1.2771479E-01
Z	-5.5705091E-01	1.1554411E 04	1.1553854E 04	6.6218516E-02
XDOT	-9.1164886E-05	4.8827666E-01	4.8818550E-01	8.6418873E-05
YDOT	-2.8981945E-04	5.0844548E 00	5.0841650E 00	5.7854939E-05
ZDOT	5.0678584E-04	2.3007348E 00	2.3012416E 00	5.2242752E-05

CURRENT RMS 91.73298
PREDICTED RMS 0.15541

TOTAL NUMBER OF OBS 240
NUMBER OF DAP ENTRIES 20

MEAN ELEMENTS FROM NEW

A	1.9912706E 00(ER)	NODE	2.6451482E 02(DEG)	NDOT	3.4981230E-04(D/DAY)
E	4.3460731E-03	OM	1.5613179E 02(DEG)	ODOT	-4.4707140E-01(D/DAY)
I	9.0000902E 01(DEG)	M	2.6978140E 02(DEG)		

ATA INVERSE

	1	2	3	4	5	6
1	0.42570E-01					
2	-0.15104E-01	0.16311E-01				
3	0.12906E-01	-0.23236E-02	0.43849E-02			
4	0.16216E-04	-0.20016E-05	0.56943E-05	0.74682E-08		
5	-0.99308E-05	0.68805E-05	-0.23225E-05	-0.26357E-08	0.33472E-08	
6	0.42381E-05	-0.65296E-05	0.24961E-06	-0.10647E-09	-0.25296E-08	0.27293E-08

NORMAL MATRIX - ATA

	1	2	3	4	5	6
1	0.56931E 06					
2	0.37368E 07	0.30287E 08				
3	-0.55296E 07	-0.51324E 08	0.95224E 08			
4	-0.15796E 10	-0.10285E 11	0.14718E 11	0.45894E 13		
5	-0.15520E 11	-0.13775E 12	0.24805E 12	0.42255E 14	0.65347E 15	
6	-0.58844E 10	-0.56718E 11	0.10756E 12	0.15842E 14	0.27917E 15	0.12297E 15

Figure 1-10. Sample Steration Summary, ADT Print

DAP OBSERVATIONS ON ADT TAPE

ID	T(MIN)	RANGE(KM)	AZ(DEG)	EL(DEG)	RDOT(KM/SEC)	SIGMA R	SIGMA A	SIGMA E	SIGMA R.
KW	226.00000	1.0907167E 04	153.60780	1.18790	-2.4451719E 00	3.0E-03	10.0E-03	10.0E-03	3.0E-05
KW	227.00000	1.0760560E 04	152.73440	2.53660	-2.4413419E 00	3.0E-03	10.0E-03	10.0E-03	3.0E-05
KW	228.00000	1.0614252E 04	151.84370	3.90270	-2.4352239E 00	3.0E-03	10.0E-03	10.0E-03	3.0E-05
KW	229.00000	1.0468382E 04	150.93360	5.28620	-2.4267179E 00	3.0E-03	10.0E-03	10.0E-03	3.0E-05
KW	230.00000	1.0323096E 04	150.00190	6.68740	-2.4157179E 00	3.0E-03	10.0E-03	10.0E-03	3.0E-05
KW	231.00000	1.0178548E 04	149.04640	8.10630	-2.4021129E 00	3.0E-03	10.0E-03	10.0E-03	3.0E-05
KW	232.00000	1.0034897E 04	148.06430	9.54300	-2.3857889E 00	3.0E-03	10.0E-03	10.0E-03	3.0E-05
KW	233.00000	9.8923091E 03	147.05300	10.99720	-2.3666269E 00	3.0E-03	10.0E-03	10.0E-03	3.0E-05
KW	234.00000	9.7509602E 03	146.00950	12.46890	-2.3445049E 00	3.0E-03	10.0E-03	10.0E-03	3.0E-05
KW	235.00000	9.6110305E 03	144.93040	13.95780	-2.3192979E 00	3.0E-03	10.0E-03	10.0E-03	3.0E-05
KW	236.00000	9.4727089E 03	143.81220	15.46340	-2.2908759E 00	3.0E-03	10.0E-03	10.0E-03	3.0E-05
KW	237.00000	9.3361920E 03	142.65090	16.98500	-2.2591089E 00	3.0E-03	10.0E-03	10.0E-03	3.0E-05
KW	238.00000	9.2016851E 03	141.44240	18.52190	-2.2238649E 00	3.0E-03	10.0E-03	10.0E-03	3.0E-05
KW	239.00000	9.0694007E 03	140.18200	20.07300	-2.1850109E 00	3.0E-03	10.0E-03	10.0E-03	3.0E-05
KW	240.00000	8.9395589E 03	138.86460	21.63700	-2.1424149E 00	3.0E-03	10.0E-03	10.0E-03	3.0E-05
KW	241.00000	8.8123884E 03	137.48480	23.21220	-2.0959499E 00	3.0E-03	10.0E-03	10.0E-03	3.0E-05
KW	242.00000	8.6881249E 03	136.03630	24.79650	-2.0454890E 00	3.0E-03	10.0E-03	10.0E-03	3.0E-05
KW	243.00000	8.5670120E 03	134.51280	26.38750	-1.9909150E 00	3.0E-03	10.0E-03	10.0E-03	3.0E-05
KW	244.00000	8.4492996E 03	132.90710	27.98220	-1.9321170E 00	3.0E-03	10.0E-03	10.0E-03	3.0E-05
KW	245.00000	8.3352441E 03	131.21150	29.57720	-1.8689959E 00	3.0E-03	10.0E-03	10.0E-03	3.0E-05

Figure 1-11. Sample Listing of DAP Observations, ADT Print

Finally, the ADT core ephemeris is printed. This is a 60 equally spaced steering history of the Millstone Hill radar, based on the new elements of the last iteration. As in the nominal core ephemeris of PREMOD, the core ephemeris consists of range, azimuth, elevation, range rate, and either:

$$\frac{\partial R}{\partial t_o}, \quad \frac{\partial A}{\partial t_o}, \quad \frac{\partial E}{\partial t_o}$$

or

$$\ddot{R}, \quad \dot{A}, \quad \dot{E}$$

The ADT core ephemeris is illustrated in Figure 1-12.

1.3.4 DAP Tape Print

1.4 MAGNETIC TAPES

The input data to MHESPOD is obtained from the BCT (Before Conditioning Tape), which is generated by PREMOD. MHESPOD output is written on the ADT (After Differential Tape) for purposes of non-real time processing.

Both tapes are in the binary mode with the exception of the first record, which is in the BCD mode. This feature allows the printing of the record only, which is for identification purposes.

1.4.1 BCT Tape Description

1) ID Record (BCD)
   - 1.1 Word 1 BCTbbb*
   - 1.2 Word 2 Satellite Number
   - 1.3 Word 3-14 Header information (from input card)

2) DAP Record
   Number of words in DAPRE
   N, DAPRE (1 - N)

*Where b = BCD blanks.

ADT CORE EPHEMERIS

T(MIN)	R2DOT(KM/SEC*2)	RANGE(KM)	AZ(DEG)	E(DEG)	RDOT(KM/SEC)	ADOT(DEG/SEC)	EDOT(DEG/SEC)
247.68333	1.2893013E-03	8.0493050E 03	126.151010	33.8234959	-1.6776597E 00	-3.3986360E-02	2.6075397E-02
245.00000	1.0885351E-03	8.3352443E 03	131.210979	29.5772741	-1.8689945E 00	-2.9055366E-02	2.6561671E-02
242.31667	8.9678519E-04	8.6494198E 03	135.561893	25.2998257	-2.0286569E 00	-2.5149071E-02	2.6501800E-02
239.63333	7.1831082E-04	8.9868697E 03	139.354197	21.0622668	-2.1584756E 00	-2.2085900E-02	2.6093881E-02
236.95000	5.5516793E-04	9.3429719E 03	142.709642	16.9086869	-2.2607786E 00	-1.9696231E-02	2.5477810E-02
234.26666	4.0784928E-04	9.7134992E 03	145.724918	12.8644292	-2.3380907E 00	-1.7839272E-02	2.4748535E-02
231.58333	2.7585025E-04	1.0094631E 04	148.476484	8.9423507	-2.3929293E 00	-1.6404173E-02	2.3968340E-02
228.90000	1.5810321E-04	1.0482945E 04	151.025097	5.1472160	-2.4276799E 00	-1.5305818E-02	2.3176612E-02
226.21667	5.3281435E-05	1.0875334E 04	153.419533	1.4788064	-2.4445322E 00	-1.4479622E-02	2.2397094E-02
223.53333	-4.0006562E-05	1.1269229E 04	155.699505	-2.0660243	-2.4454554E 00	-1.3876851E-02	2.1643026E-02
220.85000	-1.2310103E-04	1.1662060E 04	157.897888	-5.4919590	-2.4321969E 00	-1.3460877E-02	2.0920715E-02
218.16667	-1.9723102E-04	1.2051719E 04	160.042446	-8.8042998	-2.4062973E 00	-1.3204287E-02	2.0231963E-02
215.48333	-2.6348772E-04	1.2436282E 04	162.157124	-12.0083976	-2.3691107E 00	-1.3086730E-02	1.9575682E-02
212.80000	-3.2282056E-04	1.2814031E 04	164.263029	-15.1092577	-2.3218257E 00	-1.3093311E-02	1.8948955E-02
210.11666	-3.7604455E-04	1.3183423E 04	166.379248	-18.1113269	-2.2654889E 00	-1.3213402E-02	1.8347722E-02
207.43333	-4.2385315E-04	1.3543080E 04	168.523434	-21.0183306	-2.2010271E 00	-1.3439753E-02	1.7767210E-02
204.75000	-4.6683914E-04	1.3891757E 04	170.712290	-23.8331900	-2.1292581E 00	-1.3767808E-02	1.7202175E-02
202.06667	-5.0550487E-04	1.4228351E 04	172.962000	-26.5579650	-2.0509355E 00	-1.4195216E-02	1.6647065E-02
199.38333	-5.4030126E-04	1.4551840E 04	175.288439	-29.1937675	-1.9666918E 00	-1.4721269E-02	1.6096074E-02
196.70000	-5.7162869E-04	1.4861336E 04	177.707560	-31.7407844	-1.8771618E 00	-1.5346675E-02	1.5543152E-02
194.01667	-5.9989039E-04	1.5155922E 04	180.235243	-34.1981587	-1.7827752E 00	-1.6072852E-02	1.4982122E-02
191.33333	-6.2550045E-04	1.5435194E 04	182.888582	-36.5642037	-1.6841722E 00	-1.6901831E-02	1.4406069E-02
188.65000	-6.4891753E-04	1.5697968E 04	185.683193	-38.8358078	-1.5813767E 00	-1.7835135E-02	1.3808857E-02
185.96667	-6.7062122E-04	1.5944385E 04	188.637426	-41.0090418	-1.4755833E 00	-1.8874668E-02	1.3182612E-02
183.28333	-6.9124122E-04	1.6172134E 04	191.765318	-43.0790448	-1.3654498E 00	-2.0018807E-02	1.2522539E-02
180.60000	-7.1167107E-04	1.6383264E 04	195.087639	-45.0388856	-1.2530119E 00	-2.1264440E-02	1.1818135E-02
177.91667	-7.3267940E-04	1.6575049E 04	198.617188	-46.8821683	-1.1366504E 00	-2.2604659E-02	1.1065876E-02
175.23333	-7.5537382E-04	1.6747167E 04	202.368679	-48.6004910	-1.0142058E 00	-2.4025324E-02	1.0261167E-02
172.55000	-7.8122903E-04	1.6901931E 04	206.356903	-50.1824241	-8.9102719E-01	-2.5510300E-02	9.3928312E-03
169.86667	-8.1101154E-04	1.7032840E 04	210.585167	-51.6229086	-7.6008580E-01	-2.7038398E-02	8.4679159E-03
167.18333	-8.4711194E-04	1.7143657E 04	215.062401	-52.9083886	-6.2722606E-01	-2.8575649E-02	7.4752831E-03
164.50000	-8.9135410E-04	1.7235447E 04	219.784016	-54.0253043	-4.9067930E-01	-3.0078700E-02	6.4172527E-03
161.81667	-9.4489100E-04	1.7310119E 04	224.740004	-54.9606700	-3.4249120E-01	-3.1501484E-02	5.3058373E-03
159.13333	-1.0026449E-03	1.7334791E 04	229.941034	-55.7460070	-1.7572228E-01	-3.2918012E-02	4.1675369E-03
156.45000	-1.0749624E-03	1.7336361E 04	235.363887	-56.3397217	-1.9946854E-02	-3.4198036E-02	2.9536025E-03
153.76667	-1.1608347E-03	1.7352127E 04	240.905632	-56.6801472	1.5614602E-01	-3.5229003E-02	1.7207094E-03
151.08333	-1.2481481E-03	1.7298584E 04	246.702084	-56.8737178	3.3369656E-01	-3.6282797E-02	4.3978819E-04
148.40000	-1.2926134E-03	1.7164045E 04	252.853996	-56.9202580	5.7693179E-01	-3.7702623E-02	-8.4515300E-04

Figure 1-12. Sample Updated Core Ephemeris, ADT Print

3) Core Ephemeris

3.1 N, CE(1 - N)

3.2 CE(4) $\neq$ 0 CE(4) = 0

CE(4) $\neq$ 0	CE(4) = 0
t	t
$\ddot{R}$	$\dot{R}$
R	R
A	A
E	E
$\dot{R}$	$\partial R/\partial t$
$\dot{A}$	$\partial A/\partial t$
$\dot{E}$	$\partial E/\partial t$

4) COMMON (MESCOM)

N, COMMON (1 - N)

5) Pre-epoch observations

5.1 Five observations per record, 51 words in record

5.2 Format: ID, T, R, A, E, $\dot{R}$, σ_R, σ_A, σ_E, $\sigma_{\dot{R}}$.

5.3 Last record: 1, 0.

6) Physical E - Ø - F (end of file)

1.4.2 ADT Tape Description

1) ID Record (BCD)

1.1 Word 1 ADTbbb*

1.2 Word 2 Satellite number

1.3 Words 3-14 Header information (from input card)

2) Residuals Record

2.1 Data - 10 words

ID	BCD
T	Minutes from midnight, day of epoch
ΔR	Earth-radii
ΔA	Radians
ΔE	Radians
$\Delta\dot{R}$	Earth-radii/minute

*Where b = BCD blanks.

ϕ	Radians
λ	Radians
h	Feet
$\Delta\bar{R}/\dot{R}$	Minutes

2.2 Five sets per record; 51 words

2.3 Termination with two-word record: 1, 0.

3) Curve fit record

3.1 One record, 66 words, N, DATA

N	
Iteration number (1)	Integer
ΔX (6)	Earth-radii, /minutes
X_{new} (6)	Earth-radii, /minutes
Current RMS (1)	
Predicted RMS (1)	
A^TA, A^Tb, b^Tb (28)	Upper triangular by row augmented column
$(A^TA)^{-1}$ (21)	Upper triangular by row
NDAPOB (1)	Integer-number of DAP entries
POBCNT (1)	Number of observables

3.2 Residuals record, curve fit record sequencing

Residuals record
1, 0.0

Curve fit record

Residuals record
1, 0.0

Curve fit record
⋮
Curve fit record (last)
1, 1.0

4) COMMON Block

N, COMMON, (1 - N)

5) DAP observations used in curve fit

5.1 Five observations per record
51 words per record

5.2 Format

ID

T

R

A

E

$\dot{R}$

σ_R

σ_A

σ_E

$\sigma_{\dot{R}}$

Derived from DAPBUF format $\left\{\begin{array}{l} T \\ R \\ A \\ E \\ \dot{R} \\ W \end{array}\right.$

5.3 Termination with two-word record: $\boxed{1,\ 0.0}$

6) Core Ephemeris (if requested on JDC)

6.1 N, (CECI), I = 1, N)

CE (1-4) - Control words

6.2 Format

CE(4) $\neq$ 0	CE(4) = 0
t	t
$\ddot{R}$	$\dot{R}$
R	R
A	A
E	E
$\dot{R}$	$\partial R/\partial t$
$\dot{A}$	$\partial A/\partial t$
$\dot{E}$	$\partial E/\partial t$

7) Physical E - O - F (end of file)

1.5 PROGRAM STORAGE MAP

1.5.1 PREMOD COMMON

Storage Allocation and Identification—/PRECOM/PCOM (300)

Variable	Equivalence	Dimension	Description
ZONAL	1	12	Flags to identify the zonal harmonics $J_1, J_2, \cdots, J_{12}$ to be included in the force model. If 0, do not include; if $\neq 0$, include.
SECT	13	6	Flags to identify the sectorial harmonics $J_{11}, J_{22}, \cdots, J_{66}$ to be included in the force model. If 0, do not include, if $\neq 0$, include.
TESS	19	15	Code words to identify the tesserol harmonics $J_{21}, J_{31}, \cdots, J_{61}, J_{32}, J_{42}, \cdots, J_{65}$ to be included in the force model. The code words are formed as follows. If J_{nm} is desired in the model, Code word = nm The TESS list is assumed terminated when the first 0 entry is encountered.
CJ	34	12	The values of the zonal harmonics J_1, $J_2, \cdots, J_{12}$.
CJNM	46	6, 6	A two-dimensional array containing the values of the sectorial harmonics up to degree and order 6 along the main diagonal, the tesseral harmonics below the main diagonal, and the tesseral harmonic phase angles (in degrees) above the main diagonal.
CLAMNN	82	6	The values of the sectorial harmonic phase angles through J_{66}, in degrees.
POS	88	24	The Cartesian position of the moon and sun measured in ECI coordinates, referenced to the mean equator and equinox of 1950 for each of the 4 days of ephemeris card data read with the input. The storage is as follows: left superscript = day no.; right subscript = body ${}^1x_a, {}^1y_a, {}^1z_a, {}^1x_\odot, {}^1y_\odot, \cdots, {}^4z_\odot$ The coordinates are stored in units of earth radii.

Storage Allocation and Identification—/PRECOM/PCOM (300) (Continued)

Variable	Equivalence	Dimension	Description
PDEL2	112	24	The second central differences of the coordinates defined in PPOS. The storage is as follows: left superscript = day no.; right superscript = second difference left subscript = component ; subscript = body ${}^{1}_{x}\delta^{2}_{a}$, ${}^{1}_{y}\delta^{2}_{a}$, ${}^{1}_{z}\delta^{2}_{a}$, ${}^{1}_{x}\delta^{2}_{.}$, ${}^{1}_{y}\delta^{2}_{.}$, . . ., ${}^{4}_{z}\delta^{2}$
PDEL4	136	24	The fourth central difference of the coordinates defind in PPOS. The storage is as described under PDEL2.
SMAT	160	21	The a priori $A^{T}A$ normal matrix, stored upper triangular by rows, in x, y, z, $\dot{x}$, $\dot{y}$, $\dot{z}$ coordinates, in units of seconds and seconds^{-1}.
	181-210		Unused storage
SMELM	211	21	The Spadats 6-card mean elements stored in the following order: SMELM (1) a (earth radii) SMELM (2) e (3) i (radians) (4) Ω (radians) (5) ω (radians) (6) M (radians) (7) $\dot{a}$ (earth radii/day) (8) $\dot{e}$ (day^{-1}) (9) $\dot{i}$ (radians/day) (10) $\dot{\Omega}$ (radians/day) (11) $\dot{\omega}$ (radians/day) (12) N (radians/day) (13) $\ddot{a}/2$ (earth radii/day^{2}) (14) $\ddot{e}/2$ (day^{-2}) (15) O. SMELM(16) $\Omega/2$ (radians/day^{2}) (17) $\omega/2$ (radians/day^{2}) (18) N/2 (radians/day^{2}) (19) N/6 (radians/day^{3}) (20) N/24 (radians/day^{4}) (21) Not used
XICODN	232	6	The state vector as input on the STVEC NAMELIST entry, in kilometers, degrees, and seconds.

Storage Allocation and Identification—/PRECOM/PCOM (300) (Continued)

Variable	Equivalence	Dimension	Description
TJOSAV	238	1	The Julian Date at 0 hours of the epoch day associated with the ADT epoch. This cell allows DAPOB to compute the proper time lag for ADT observations being used on ensuring MESPOD runs.
IPADT	239	1	Column 20 of the JDC. If = 1, print ADT; if = 2 include print of core ephemeris; if = 0 do not print ADT.
IRADT	240	1	Column 21 of the JDC. If = 0, no ADT restart; if $\neq 0$ use ADT for restart.
IGBCT	241	1	Column 25 of the JDC. If $\neq 0$, generate BCT.
ISEN	242	1	Column 31 of the JDC. If $\neq 0$, process station location cards.
IOBS	243	1	Column 32 of the JDC. If $\neq 0$, process observation cards.
ICEFLG	244	1	Column 33 of the JDC. If = 0, core ephemeris to contain $R, A, E, \partial R/\partial t, \partial A/\partial t, \partial \epsilon/\partial t, \dot{R}$ if $\neq 0$, the core ephemeris will contain: $R, A, E, \dot{R}, \dot{A}, \dot{E}, \ddot{R}$
IRESD	245	1	Column 34 of the JDC. If $\neq 0$, record residuals or ADT during MESPOD curve fit.
DRAGCD	246	1	If non-zero, the value of C_d, the drag coefficient. The user will input either C_d, A, m σ C_d A, m if drag is to be specified.
DRAGA	247	1	If non-zero, the value of the effective area of the spacecraft to be used in the simulation of atmospheric drag, (meters squared).
DRAGM	248	1	If non-zero, the value of the mass of the spacecraft to be used in the simulation of atmospheric drag (hilograms).

Variable	Equivalence	Dimension	Description
RPGAM	249	1	If non-zero, the value of γ to be used in the radiation pressure calculations. The user will either specify γ, A and m individually or $\gamma A/m$ directly.
RPA	250	1	If non-zero, the value of the effective area of the spacecraft for use in calculating the effects of solar radiation pressure (meters squared).
RPM	251	1	If non-zero, the value of the mass of the spacecraft to be used in calculating the effects of solar radiation pressure (kilograms).
DRAG	252	1	The value of C_dA/m from the NAMELIST input name DRAG in units of meters squared per kilogram.
RADPR	253	1	The value of $\gamma A/m$ from the NAMELIST input name RADPR in units of meters squared per kilogram.
PTB	254	3	The specification of the preliminary epoch time TB, the point at which the search for rise is to be initiated. This time is given in days, hours, and minutes from the input epoch (TIME entry through namelist or the time entries on the SPADATS 6-card element sat). Either PTB(1-3) or PTNULL(1-3) may be specified, not both.
PTNULL	257	3	The specification of the epoch to be used by MESPOD in days, hours, and minutes from the input epoch.
DAYLNT	260	1	Integral modified Julian Date from SPADATS 6-card element set.
DAYFRC	261	1	Fractional Julian Date from SPADATS 6-card element set.
IPRCE	262	1	Column 35 of the JDC. If = 0, do not place core ephemeris on ADT following final iteration of MESPOD. If $\neq 0$, do place core ephemeris on ADT. This column must be set when generating the BCT if it is desired to later print the core ephemeris from the ADT.

Storage Allocation and Identification — /PRECOM/PCOM (300)(Continued)

Variable	Equivalence	Dimension	Description
IDAPT	263	1	Column 19 of the JDC. If $\neq 0$, print the DAP row-averaged data tape.
KDAP	264	1	Logical tape number of DAP raw-averaged data.
	265-300		Not used.

1.5.2 MHESPOD Common Storage Map/MESCOM/MCOM (900)

Name	MCOM( )	Dimension	Definition of Variable or Array
CWE	1	1	Earth's rotational rate (radians per minute) ω_e
CELLIP	2	1	Ellipticity of the earth
CMU	3.	1	GM of the earth (earth radii^3/min^2)
CGMR	4	2	GM ratios (moon, sun) to earth
CFTER	6	1	Conversion from earth radii to feet
CKMER	7	1	Conversion from feet to kilometers
CKMER	8	1	Conversion from earth radii to kilometers
CMTER	9	1	Conversion from earth radii to meters
CDEG	10	1	Conversion from radians to degrees
CFTNM	11	1	Conversion from nautical miles to feet
CDAYMN	12	12	Cells containing number of days in each month
CPI	24	1	π
C2PI	25	1	2π
KOUT	26	1	Output tape number (print)
KIN	27	1	Input tape number
KBCT	28	1	Before conditioning tape number (BCT)
KADT	29	1	After differential correction tape number (ADT)
CHMAX	30	1	Maximum step size (minutes)
CHMIN	31	1	Minimum step size (minutes)
CYMIN	32	1	Parameter for variable step integration
CER	33	1	Parameter for variable step integration
CBE	34	1	b_e
CRASHE	35	1	Impact test parameter

Name	MCOM( )	Dimension	Definition of Variable or Array
CRASHM	36	1	Altitude to start testing for impact
NRRR	37	1	Non-zero for fixed step Runge-Kutta
TNULL	38	1	Pre-specified epoch (minutes)
TB	39	1	Preliminary epoch (minutes)
TF	40	1	Maximum length of core ephemeris
TNODE	41	1	Final time of core ephemeris
TEPOCH	50	1	Epoch time, minutes from midnight
TJDATE	51	1	Julian date of midnight, epoch day
DYEAR	52	1	Epoch year
DMNTH	53	1	Epoch month
DDAY	54	1	Epoch day
DHOUR	55	1	Epoch hour
DMIN	56	1	Epoch minutes
DSEC	57	1	Epoch seconds
DTYPE	58	1	Initial conditions type
DBASE	59	1	Number days from 1950 to day of epoch
TALFAG	60	1	α_g for midnight day of epoch (radians)
CDAD2M	61	1	$C_d A/2m$ (feet^2/slug)
TSTEP	62	1	Nominal step size (minutes)
TNOMX	63	6	Initial Cartesian coordinates (x, y, z, $\dot{x}$, $\dot{y}$, $\dot{z}$)
TICRT	69	6	Nominal Cartesian coordinates
NITER	75	1	Maximum number of iterations
NOOBS	76	1	Number of pre-epoch observations
N1	77	1	Counters for geopotential routine
N2	78	1	Counter for geopotential routine

Name	MCOM( )	Dimension	Definition of Variable or Array
N3	79	1	Counter for geopotential routine
FJ	80	12	Working storage for generalized geopotential subroutine
C	92	6, 6	Working storage for generalized geopotential subroutine
NPR	164	1	Total number of parameters to solve for
NDPR	165	1	Total number of Category 1 variables to solve for
NAROW	166	1	Starting location where one row of the augmented matrix (A, B) is stored
NBDNS	167	1	Starting location of the bounds vector
NPAR	168	1	Identifies current values of parameters in solution vector
NDPAR1	169	1	Identifies correction vector
NSCALE	170	1	Identifies solution vector scale vector
NATA	171	1	Identifies A^TA, A^TB stored upper triangular by rows
NR	172	1	Identifies $(A^TA)^{-1}$
NSTAT	173	1	Starting location of master sensor table in variable storage
SKIP	174	1	If 0, set FLVE = 0, if non-zero, set FLVE accordingly
SGAMAM	175	1	$S(\gamma A/m)$ radiation pressure constant
XJD	176	4	Array of Julian dates (mod 2430000.) in core storage for ephemeris of moon and sun
POS	180	4, 3, 2	Positions of moon and sun correspondint to XJD
DEL2	204	4, 3, 2	2nd central differences of position of the moon and sun corresponding to XJD
DEL4	228	4, 3, 2	4th central differences of position of the moon and sun corresponding to XJD

Name	MCOM( )	Dimension	Definition of Variable or Array
SIGMH	252	4	σ's for Millstone—applied to DAP observations
IRESFG	256	1	= 0 Do not record residuals on ADT ≠ 0 Record residuals on ADT
CEP1	257	1	P_1 used in generating core ephemeris
IRCE	258	1	= 0 Do not record core ephemeris on ADT ≠ 0 Record core ephemeris on ADT
NDAPOB	269	1	Number of DAP observations used in curve fit
FLVE	270	1	= 0 Integrate variational equations ≠ 0 Skip VAREQ on corrector step
TEMP	271	50	Temporary working storage
TRAJX	321	57	See P. 4-352, ESPOD Mathematical and Subroutine Description
TLIST	378	192	Numerical integration working storage
TG	570	1	Time to integrate to (minutes)
TMINUS	571	1	Flag to indicate integration time before epoch
TUBSEF	572	1	EOF flag for reading observations
TRHOA	573	1	Density of air, slugs/ft^3
TALT	574	1	Altitude of vehicle in feet
TDRAG	575	3	Three components of acceleration due to drag
TV	578	3	Three components of earth-fixed velocity
TVA	581	1	Magnitude of earth-fixed velocity
TR	582	1	R, magnitude of position vector of vehicle
TR2	583	1	R^2
TR3	584	1	R^3

Name	MCOM( )	Dimension	Definition of Variable or Array
TR5	585	1	R^5
TR7	586	1	R^7
TPOT	587	3	Total acceleration due to earth's potential field
COLA	590	1	Cosine ϕ, where ϕ = latitude
SILA	591	1	Sine ϕ
SIPH	592	1	Sin λ, where λ = longitude
COPH	593	1	Cos λ
SNALF	594	1	Sin α, α = right ascension
CSALF	595	1	Cosine α
XN	596	6	Position of moon and sun in component form
TRPRES	602	3	Three components of acceleration due to radiation pressure
TBPERT	605	3	Three components of acceleration due to bodies
TCRASH	608	1	Flag non-zero when impact occurs
PMAT	609	9	Matrix used in evaluating variational equations
VMAT	618	9	Matrix used in evaluating variational equations
PUBS	627	6	Sensor ID, time, R, A, E, $\dot{R}$ table
PSTAT	633	10	Working storage for sensor information
PCSALF	643	1	Cos α_g, where $\alpha_g = \alpha g_o + \lambda + \omega_e t$
PSNALF	644	1	Sin α_g
PWI	645	3	Vector (w_1, w_2, w_3)
PWDTI	648	3	Vector $(\dot{w}_1, \dot{w}_2, \dot{w}_3)$
PUI	651	3	Vector (u_1, u_2, u_3)

Name	MCOM( )	Dimension	Definition of Variable or Array
PVI	654	3	Vector (V_1, V_2, V_3)
PV	657	1	$\left(V_1^2 + V_2^2\right)^{1/2}$
PRSUB1	658	1	$R_1 = V_R$
PSNE	659	1	Sin E_c
PCSE	660	1	Cosine E_c
PSNA	661	1	Sin A_c
PCSA	662	1	Cos A_c
PCMR	663	1	R = computed slant range
PWPP	664	18	Partial derivatives (see PRELIM subroutine write up)
PWDTPP	682	18	Partial derivatives (see PRELIM subroutine write up)
PRESD	700	4	Residuals array (measured-computed)
IPFRST	704	1	0 to indicate first time in RADR
PLSTSN	705	1	Number of last sensor processed by RADR
PUDTI	706	3	Vector $(\dot{u}_1, \dot{u}_2, \dot{u}_3)$
PSIG	709	4	Sigma list for current station and associated time and observations
POBCNT	713	1	Total number of accepted observations
TSUS	714	1	Current total RMS
TSUSP	715	1	Predicted RMS for next iteration
IFTEX	716	1	= 0 iterations not completed $\neq$ 0 max iterations
NITCT	717	1	Iteration counter
VSTR	718	155	Floating point variable storage

2. NRTPOD

2.1 GENERAL PROGRAM CHARACTERISTICS

NRTPOD is a general purpose orbit determination program prepared for use by the Massachusetts Institute of Technology Lincoln Laboratory at the Millstone Hill Radar Site. The program is a derivative of the program "ESPOD" which was originally developed for the SPACETRACK/SPADATS Center, Ent Air Force Base, Colorado. NRTPOD is an improved version of the parent program and is specifically limited in size such that it will operate in the real time computer system at the Millstone Hill Radar Site.

The primary purpose of the program is to determine the elements of a satellite orbit and a covariance matrix of uncertainty in the determination, given some initial estimate of the orbit. From the best elements obtained, the program predicts the future position and velocity of the satellite. The program includes a sophisticated collection of mathematical, statistical, and operational techniques to make it operate rapidly, and produce high precision in the results.

2.1.1 General Orbit Model

NRTPOD utilizes a Cowell method of special perturbations for propagating the satellite position and velocity. The process is initiated with a Runge-Kutta starter which sets up the finite differences from which the Cowell integration proceeds. At each given time, the influences of all the forces acting on the satellite are calculated and summed. These forces are dependent entirely upon the position and velocity of the satellite at a given time; that is, they are special for the moment. The integration step size is automatically controlled to keep seventh-order differences in acceleration within a certain numerical range. This technique guarantees a certain accuracy but permits the step size to be as large as possible.

The NRTPOD Program provides a recursive computation technique for calculating the perturbative acceleration of a satellite resulting from the fact that the earth is not a homogeneous sphere. Nominally, only the first three zonal harmonics and the second sectorial harmonic are used;

however, the first nine zonal harmonics and all sectorial and tesseral harmonics through order and degree four may be used.

Atmospheric drag is derived as a force tangent to the direction of travel of the satellite, jointly proportional to a drag parameter and the density of the atmosphere. The drag parameter assumes the familiar form of ballistic drag; i.e., $C_D A/m$. The atmospheric density profile is calculated as specified by the Lockheed-Jacchia Model.

The perturbing effects of the sun and moon on an earth satellite are simulated in the mathematical model of NRTPOD. If the perturbation effect is desired, the ephemerides of the sun and moon are entered on cards.

An improved version of the radiation pressure model has been incorporated into NRTPOD (and PREMOD-MHESPOD). The new radiation pressure model accounts for reflected radiation from the earth, is inactive when the vehicle is in earth shadow, and approximates the eclipse zone with atmospheric refraction considerations.

2.1.2 Differential Correction

Since no set of observations obtained from a tracking system can be fit to a trajectory perfectly, only an estimate of the actual trajectory can be made. Like most curve fitting programs, NRTPOD uses a weighted least squares method of forming the best estimate from the observations available. In the simplest case, only the position and velocity components are to be computed; all other parameters and constants are assumed to be known exactly. In addition to solving for six components of position and velocity, NRTPOD may include other non-orbital parameters, such as drag parameters, observation biases, and station location coordinates. The final elements are achieved by iterating on the differential correction procedure. Convergence is obtained when the sum of the squares of the weighted residuals changes by less than 0.1 percent due to the last computed correction.

Since the differential correction process depends upon the appropriateness of a linear approximation to a nonlinear function, linear theory may fail if finite corrections become too large. In order to keep the corrections within a linear region, bounds are used on the individual solution components. This is a desirable technique which is automated in

NRTPOD, increasing its ability to converge to correct elements. The bounds are adjusted automatically to compensate either for diverging corrections or for too slow convergence. Whenever a "correction" results in a divergence, i. e., the new orbital elements yield a larger sum of squares of weighted residuals than the previous elements, the bounds are halved and a new, more constrained solution is attempted. If this fails to achieve a convergent iteration, the bounds are halved again until one-eighth bounds have been tried. At this point, the program exits. On the other hand, if a correction yields a new sum of squares of weighted residuals which actually is less than the previous sum, the bounds are doubled, permitting larger corrections. However, when the actual sum of squares is not within 10 percent of a previously predicted sum, the bounds remain unchanged. When the actual sum and the predicted sum are not in close agreement, nonlinearity is indicated.

2.1.3 Research Capability

NRTPOD is primarily an operational program. The program structure permits the analyst to change any constants defining the mathematical models, to change the weights applied to residuals, to change other sensor parameters, to weight a priori estimates, to force the integration to particular step sizes, to change any physical constants, etc. With this convenience, NRTPOD can be used as a research tool. The effect of varying the potential model, the solution of observation biases, and inclusion of all data points from intensive tracking, can be studied for general or particular influence on many types of satellites.

2.1.4 General Computational Logic Flow

A general logic flow of the NRTPOD Program is outlined on the next page. The differential correction process is outlined in sequential steps as the computational procedure is not a straightforward as other options such as trajectory propagation. Detailed logic flows of the particular subroutines which perform the indicated mathematical and logic operations can be found in the subroutine section of this document.

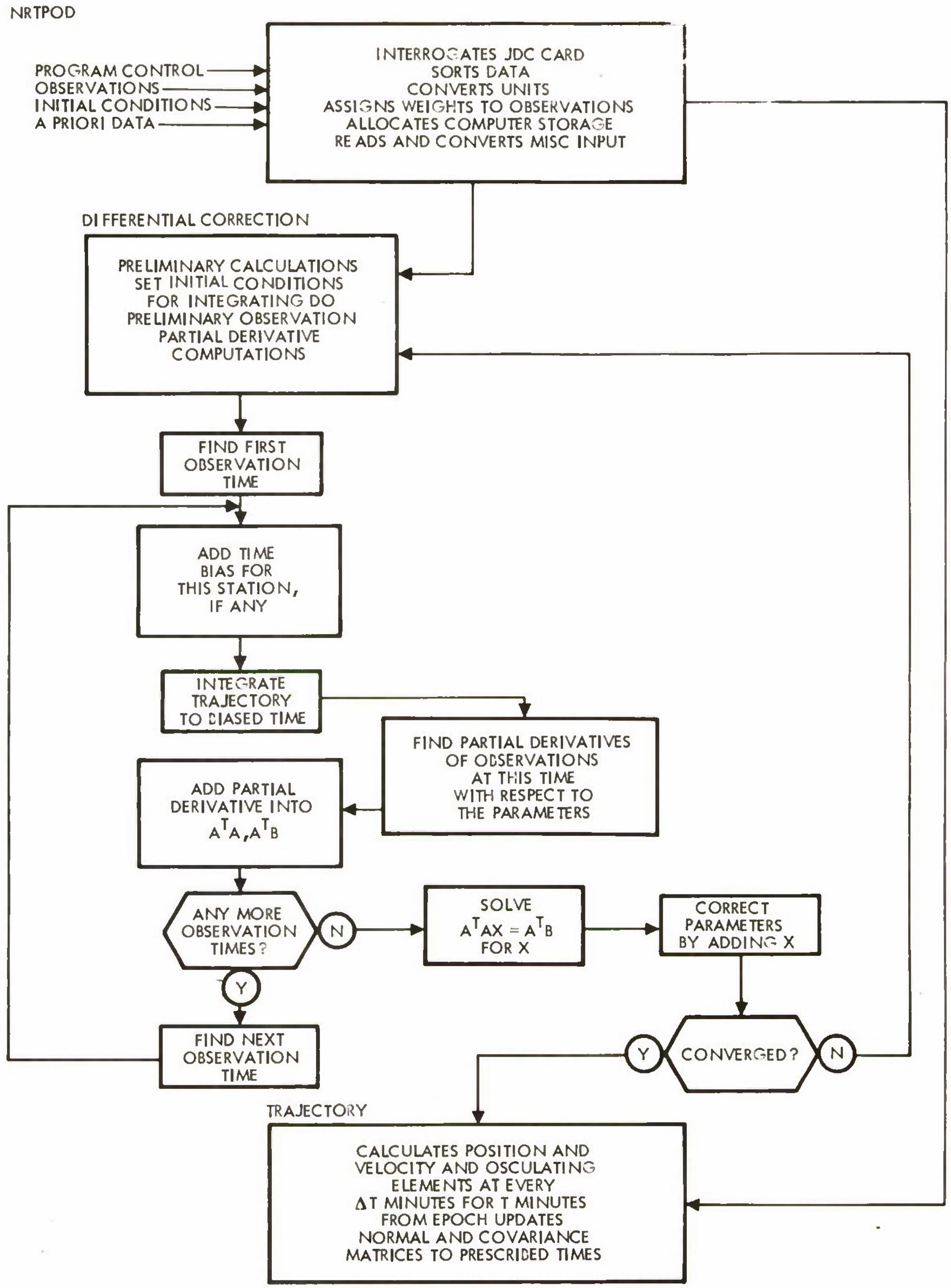


Figure 2-1. General Logic Flow of the NRTPOD Program

2.2 NRTPOD INPUT

The NRTPOD input and deck set-up is similar to the formats and conventions described in the PREMOD-MHESPOD input section (1.2). Many of the input variables common to both programs have identical call names and card formats.

2.2.1 Deck Set-Up

The input deck must always begin with the JDC card. In the simplest set-up, an input deck would consist of a JDC card and preliminary data inputs. With this configuration, trajectory and matrix update runs can be made. From the sample input deck on the following page, the deck sequence and those parts of the deck that are mandatory under various conditions can be seen. If the ephemeris cards are left out of the deck, the program will function normally, except that the perturbations due to the sun and moon will be ignored. Also, it should be noted that ephemeris cards are required if radiation pressure is called, since the position of the sun is obtained from them. The order of the sensor cards within the sensor card sub-deck is immaterial. Depending on the particular run, there may be up to three sensor cards (see Section 1.2.5) per sensor. If there are fewer than 345 observation cards, they may be input in random sequence. If there are more than 345 observations, the cards must be in chronological sequence, the first card being nearest epoch. (See Figure 2-2.)

2.2.2 JDC - Job Description Card

The JDC card is the control card for the flow of information through NRTPOD. This card is always the first card of an input data deck. It selects certain program options and defines the program sections to be used. A short arbitrary remark is permitted on the card.

Column	Content	Description
1-3	JDC	Identifies JDC card
4-7		Vehicle number (optional)
8-17		Vehicle name (optional)
18-29		User's header
30	Not used at present	

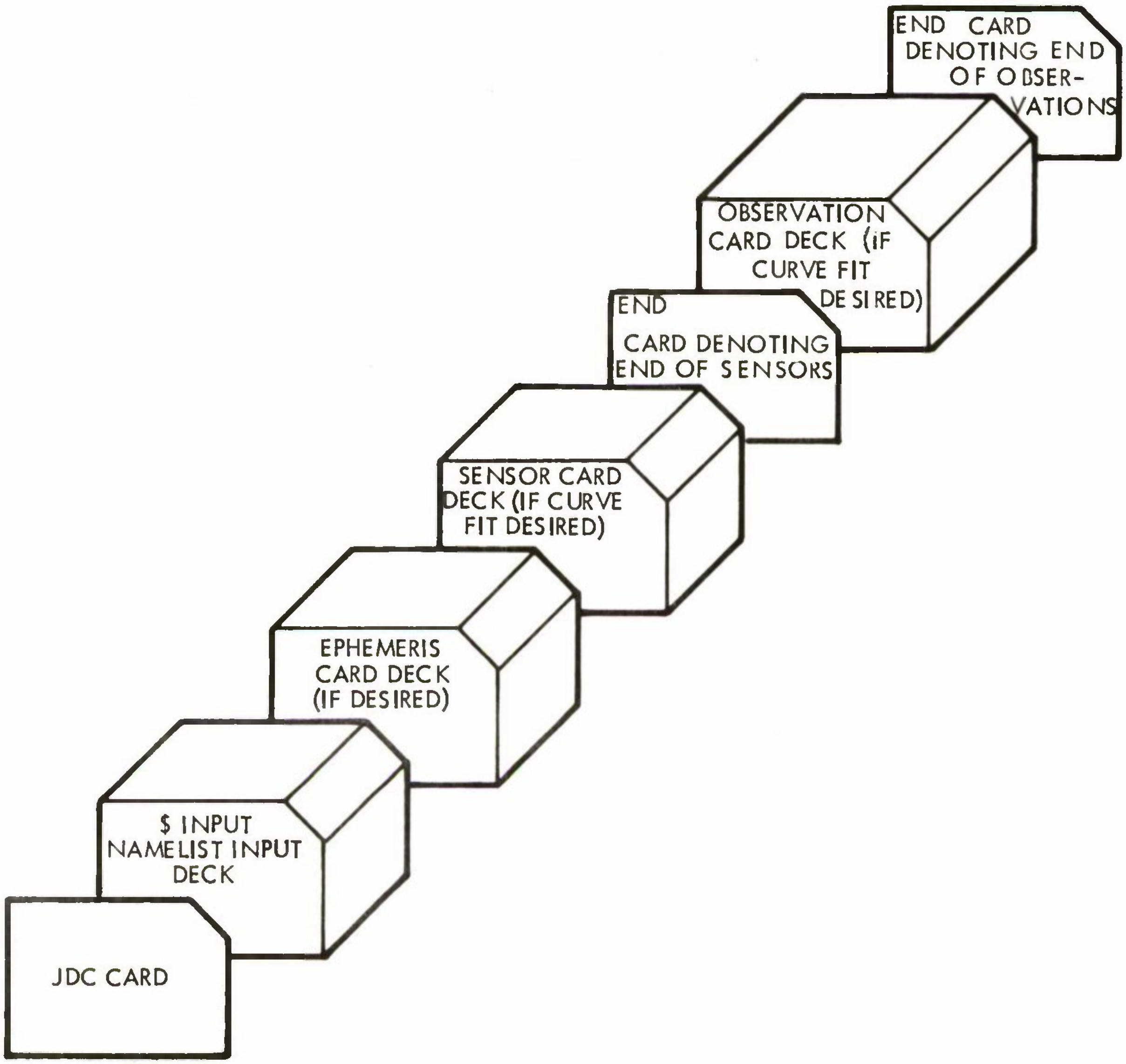


Figure 2-2. NRTPOD Sample Input Deck

Column	Content	Description
31	0 or blank	Sensor and observation data not be be processed
	1	Sensor and observation data to be processed
32	0 or blank	Do not print sensor data
	1	Print sensor data
33	0 or blank	Do not print observations
	1	Print observations
34-40	Not used at present	
41	0 or blank	Curve fit not desired
	1	Curve fit desired
42	0 or blank	A priori S matrix not input this run
	1	A priori S matrix is input on this run
43-50	Not used	
51	0 or blank	Trajectory print not desired this run
	1	Trajectory print is desired this run
52	0 or blank	A priori UPMAT (covariance) matrix not input
	1	A priori UPMAT matrix is input this run
53-54	Not used	
55	0 or blank	Covariance matrix update not desired
	1	Covariance matrix update desired this run

2.2.3 Preliminary Data Input

The preliminary data cards are in the NAMELIST format, as they are for PREMOD-MHESPOD. Many of the inputs are identical to PREMOD-MHESPOD; however, all input variables names which are acceptable to NRTPOD are enumerated in this section as not all inputs of PREMOD-MHESPOD are used in NRTPOD.

The description of the input variables is given on the following pages. The dimension of the input array is indicative of the maximum number of entries for a given variable.

NAMELIST INPUT

Variable Name	Dimension	Description
COM	60	Variables in BLK1 blank COMMON
DRAG	1	Ballistic coefficient (C_DA/m) (meters^2/milogram)
or		
DRAGCD	1	Terms may be input in place of DRAG: C_D coefficient of drag
and		
DRAGA	1	A area in ballistic coefficient term (meters^2)
and		
DRAGM	1	m mass in ballistic coefficient term (kilograms)
CNSIG	1	N for N(σ) deletion (nominally 1000)
TIME	6	Epoch time in YR, MO, DAY, HR, MIN, SEC.
DELTT	17	Sets of Δt, t trajectory print (maximum 8 sets). Trajectory points printed for Δt increments over interval t minutes from epoch.
BNDS	50	Bounds specified to control convergence for each CAT1 or CAT2 variable selected for solution.
NITER	1	No. of iterations desired in curve fit (nominally 1)
STVEC	6	Array identifying the initial position and velocity for the following coordinates: 1. (TYPE no. 1) ECI polar spherical α, δ, β, A, R, V (deg., km., km/sec)

Variable Name	Dimension	Description
		2. (TYPE no. 2) ECI Cartesian $x, y, z, \dot{x}, \dot{y}, \dot{z}$ (km, km/sec) 3. (TYPE no. 3) ECI polar spherical $\lambda, \delta, \beta, A, R, V$ (deg, km, km/sec)
CAT1	8	Category 1 variables: CAT1(1) Right ascension, α CAT1(2) Declination, δ CAT1(3) Flight path angle, β CAT1(4) Azimuth, A CAT1(5) Radius, R CAT1(6) Velocity, V CAT1(7) Drag parameter, C_DA/m CAT1(8) Not used. The CAT1 array indicates to the program the Category 1 variables to be solved for. This array must contain either "ones" or "zeros." A "1" indicates that the corresponding variable is to be solved for. A "0" indicates that the corresponding variable is not to be solved for. This convention holds true for seven Category 1 variables. For example, a NAMELIST card punched as follows CAT1 = 1, 1, 0, 1, 1, 0, 0, indicates that on this run, the variables α, δ, A, and R are to be solved and that β, V, C_DA/m will be held constant.
CAT2	225	Category 2 variables: CAT2(1) Station ID 9Hollerith) CAT2(2) Range bias, R_b, flag

Variable Name	Dimension	Description
		CAT2(3) Azimuth bias, A_b, flag CAT2(4) Elevation bias, E_b, flag CAT2(5) Range rate bias, $\dot{R}_b$, flag CAT2(6) Time bias, t_b, flag CAT2(7) Latitude bias, ϕ_b, flag CAT2(8) Longitude bias, λ_b, flag CAT2(9) Height bias, h_b, flag CAT2(10) . . . CAT2(18) Next station biases, if any CAT2(19) . . . CAT2(27) Next station biases, if any The CAT2 array indicates to the program, the Category 2 variables (biases) to be solved for selected sensors. Any combination of CAT2 variables may be solved for the same sensor. The convention for specifying CAT2 variables to be solved is similar to that used in CAT1 cards. For example, NAMELIST cards punched as follows: CAT2 = 0, 1, 1, 1, 0, 0, 0, 0, 1 $.REDEF CAT2 = H CAT2(1) = CP indicate that R_b, A_b, E_b, and h_b of sensor CP are to be solved for.
COM3	100	Variables in BLK3 blank COMMON
TYPE	1	Indicates type of initial conditions (position and velocity) input by the STVEC array.

Variable Name	Dimension	Description
		TYPE = 1 Indicates ECI polar spherical inputs α, δ, β, A, R, V TYPE = 2 Indicates ECI Cartesian inputs X, Y, Z, $\dot{X}$, $\dot{Y}$, $\dot{Z}$ TYPE = 3 Indicates ECI polar spherical λ, δ, β, A, R, V
BISES	50	Bias estimates: Identifies the start of an array which contains the initial bias estimates of the Category 2 variables in the differential correction vector. They are specified in the same order as that for bounds. <u>If any Category 2 initial estimate is specified, all must be specified.</u> If a particular initial estimate is not known, zero (0.0) may be entered.
UPMAT	28	<u>A priori</u> covariance matrix: (Col. 52 on JDC card) Restricted to being a 6 x 6 or 7 x 7 depending on whether drag is or is not included, this covariance matrix resulting from a previous differential correction can be made available for propagating uncertainties. The UPMAT matrix is symmetric and only the lower triangular portion is input. As an example, a 6 x 6 matrix is illustrated showing the order of assigning matrix elements to the UPMAT array.

Variable Name	Dimension	Description
		$\begin{array}{llllll} u_{11} & & & & & \\ u_{21} & u_{22} & & & & \\ u_{31} & u_{32} & u_{33} & & & \\ u_{41} & u_{42} & u_{43} & u_{44} & & \\ u_{51} & u_{52} & u_{53} & u_{54} & u_{55} & \\ u_{61} & u_{62} & u_{63} & u_{64} & u_{65} & u_{66} \end{array}$ UPMAT(1) = u_{11} $\left.\begin{array}{l} \text{UPMAT(2)} = u_{21} \\ \text{UPMAT(3)} = u_{22} \\ \text{UPMAT(4)} = u_{31} \\ \text{UPMAT(5)} = u_{32} \\ \quad\vdots \end{array}\right\}$ Input is lower triangular by rows. UPMAT(21) = u_{66}
SMAT	210	_A priori_ normal matrix (A^TA) NRTPØD can accept an _a priori_ A^TA matrix (input flag on column 42 of JDC card) which brings into the differential correction summarized data from observations already processed on previous runs of NRTPOD. The _a priori_ A^TA-matrix will be valid only if the initial conditions for the new differential correction are the same set which generated the _a priori_ A^TA-matrix. Note that the new differential correction will cause the initial conditions to vary from iteration to iteration. Hence, the _a priori_ A^TA-matrix is valid for only one iteration. The _a priori_ A^TA-matrix (S-matrix) is input as an upper triangular by

Variable Name	Dimension	Description
		rows matrix. The total number of variables input is N(N+1)/2, the maximum order being 20. The following example indicates the placement of elements for a 5 x 5 S-matrix

$$
\begin{matrix}
S_{11} & S_{12} & S_{13} & S_{14} & S_{15} \\
 & S_{22} & S_{23} & S_{24} & S_{25} \\
 & & S_{33} & S_{34} & S_{35} \\
 & & & S_{44} & S_{45} \\
 & & & & S_{55}
\end{matrix}
$$

Since the A^TA is symmetric the input of SMAT is upper triangular by rows,

SMAT(1) = S_{11}
SMAT(2) = S_{12}
SMAT(3) = S_{13}
SMAT(4) = S_{14}
SMAT(5) = S_{15}
SMAT(6) = S_{22}
SMAT(7) = S_{23}
SMAT(8) = S_{24}
SMAT(9) = S_{25}
SMAT(10) = S_{33}
SMAT(11) = S_{34}
SMAT(12) = S_{35}
SMAT(13) = S_{44}
SMAT(14) = S_{45}
SMAT(15) = S_{55}

Variable Name	Dimension	Description
DELET	100	Input provided to edit residuals and to reject those which are not to be included in the differential correction DELET marks the beginning of a

Variable Name	Dimension	Description
		table of identification numbers of residuals to be deleted. The identification numbers are taken from the residuals listing of a previous NRTPOD computer run. DELET entries are specified in pairs (a, b) which mark respectively the first and last residual of a list of residuals to be deleted. The program deletes all residuals whose identification number lies between a and b inclusive. If a = b, a single residual is deleted. Up to 50 sets of (a, b) pairs may be input through the DELET array.
CKRMS	1	A provision for editing residuals by input. Residuals may be rejected from the differential correction by comparison with some multiple (CKRMS) of the root mean square of the weighted residuals from the previous iteration.
DTMAX	1	A provision for editing residuals by input. Residuals may be rejected from the differential correction if the corresponding observations are removed more than some arbitrary time in days (DTMAX) from epoch. Nominally, 20 days.
NDAYS	1	Indicates to the INPUT link of NRTPOD the number of days of ephemeris input for a particular case. These ephemeris data include the

Variable Name	Dimension	Description
		position of the sun and the moon along with 2nd and 4th central differences of these positions. If NDAYS is not specified, the program assumes NDAYS = 0 and does not expect any ephemeris cards to be input. If NDAYS ≠ 0 is specified, the input number of days of ephemeris data must correspond exactly. Note: If NDAYS = 0, perturbations due to radiation pressure and due to the accelerations of the sun and moon are not included in the trajectory simulation.
BFLAGS	2	Flags indicating to NRTPOD whether perturbations due to the accelerations of the sun and moon are to be included in the trajectory simulation. Nominally, BFLAGS(1) (moon flag), and BFLAGS(2) (sun flag) are set non-zero, indicating both bodies are to be considered. A zero input to BFLAGS excludes the corresponding body (moon or sun) from the simulation.
RADPR	1	Radiation pressure parameter, $\frac{\gamma A}{m}$ (meters^2/kilogram). A non-zero entry for RADPR calls the radiation pressure option. Also, γ, A, m may be input individually through RPGAM, RPA, RPM. Note: NDAYS must be specified non-zero, with corresponding ephemeris input, when radiation pressure parameters are input.

Variable Name	Dimension	Description
RPGAM	1	Radiation pressure parameter, γ, reflectivity constant.
RPA	1	Radiation pressure parameter, A, effective area of the vehicle in square meters.
RPM	1	Radiation pressure parameter, m, mass of the vehicle in kilograms.
		(RPGAM, RPA, RPM: Terms may be input in place of RADPR)
ZONAL	12	Array of cells used for callouts of the coefficients of the zonal harmonics $J_2, \cdots, J_{12}$. A "1" in the ZONAL word indicates that the corresponding coefficient of the spherical harmonic is to be included. ZONAL(2), ZONAL(3), ZONAL(4) are nominally set to "1" by the program which indicates that J_2, J_3, and J_4 are included in the simulation.
CJ	12	Values of the coefficients of the zonal harmonics $J_2, \cdots, J_{12}$, may be altered on input through the CJ array, CJ(2), $\cdots$, CJ(12).
SECT	6	Array of cells used for callouts of the sectional harmonics, non-zero to include the desired harmonic. SECT(2) nominally set = 1. $(J_2^2, J_3^3, \cdots, J_6^6)$
TESS	15	Array of code words for selection of tesseral harmonics, where each cell is of the form $N > 10 + M$ where N is the degree and M the order of the desired tesseral.

Variable Name	Dimension	Description
		For example, if two of the desired tesserals to be included is J_2^1 and J_3^1, a NAMELIST card "TESS = 21, 31" must be included.
CLAMNN	6	Array containing values of the angles associated with the coefficients of the tesseral harmonics $\lambda_2^2, \lambda_3^3, \cdots, \lambda_6^6$ where CLAMNN(2) = λ_2^2 CLAMNN(3) = λ_3^3 . . . CLAMNN(6) = λ_6^6
CJNM	6, 6	Six by six array containing the coefficients of the sectorial and tesseral harmonics and their associated angles. The CJNM matrix contains $J_1^1, J_2^2, \cdots, J_6^6$ along the main diagonal, $J_2^1, J_3^1, \cdots, J_6^5$ below the diagonal and $\lambda_2^1, \lambda_3^1, \cdots, \lambda_6^5$ above the diagonal

$$\text{CJNM} = \begin{bmatrix} J_1^1 & \lambda_2^1 & \lambda_3^1 & \lambda_4^1 & \lambda_5^1 & \lambda_6^1 \\ J_2^1 & J_2^2 & \lambda_3^2 & \lambda_4^2 & \lambda_5^2 & \lambda_6^2 \\ J_3^1 & J_3^2 & J_3^3 & \lambda_4^3 & \lambda_5^3 & \lambda_6^3 \\ J_4^1 & J_4^2 & J_4^3 & J_4^4 & \lambda_5^4 & \lambda_6^4 \\ J_5^1 & J_5^2 & J_5^3 & J_5^4 & J_5^5 & \lambda_6^5 \\ J_6^1 & J_6^2 & J_6^3 & J_6^4 & J_6^5 & J_6^6 \end{bmatrix}$$

2.2.4 Sensor Cards

The NRTPOD sensor cards are identical to the PREMOD-MHESPOD card formats. See Section 1.2.5 for description.

2.2.5 Observation Cards

The NRTPOD observation cards are identical to the PREMOD-MHESPOD card formats. See Section 1.2.6 for description.

2.2.6 Ephemeris Cards

NRTPOD requires that ephemeris cards be input if the effects of lunar and solar perturbations and/or radiation pressure are to be included in the mathematical model. The card format is identical to the PREMOD-MHESPOD ephemeris cards as described in Section 1.2.7.

The four ephemeris cards as described in Section 1.2.7 must be input for each day of ephemeris input. A minimum of 4 days of lunar-solar ephemeris cards must be input to NRTPOD if perturbations of acceleration due to the moon and sun and/or radiation pressure perturbations are to be simulated in the trajectory model.

No ephemeris cards are required if these perturbations are not to be simulated. The maximum number of days of lunar-solar ephemeris cards accepted by NRTPOD is 10, if the input data require this amount.

If ephemeris cards are input, in other words, if NDAYS (NAMELIST INPUT) is set, NRTPOD expects NDAYS days worth of ephemeris cards placed directly behind the NAMELIST input cards in the data deck. See section 2.2.1 for a description of the NRTPOD input deck.

2.3 PRINTED OUTPUT

The NRTPOD output is an off-line printout. The output is sectioned into one or more pages of particular information. The sections are outlined below with reference to the particular description which are supplemented with sample printout.

Data	No. of Pages	Section
Input Listing	1	2.3.1
Run Header	1	2.3.2
Observations	1 or more	2.3.3
Residuals	1 or more	2.3.4
Mean and Standard Deviations by Sensor	1	2.3.5
Iteration Summary	1	2.3.6
Trajectory Print	1 or more	2.3.7
Matrix Update	1 or more	2.3.8

2.3.1 Input Listing

This page lists the NAMELIST input cards beginning with the $ INPUT card. The columns in the listing correspond to the punched columns in the input cards and are a quick and convenient check for proper input to the run. Figure 2-3 shows a sample input listing page. The JDC card is printed on the page immediately preceding the input listing page.

2.3.2 Run Header Data

The run identification data, the initial conditions, and the sensor information comprise the Run Header page. These data identify the run, presents the initial conditions in standard coordinate systems, and labels certain input quantities. Figure 2-4 is a sample Run Header page. Each line is described as follows:

Line No.	Line Description
1	Program name — ORBIT DETERMINATION PROGRAM — NRTPOD
2	Vehicle number — from columns 4-7 of JDC Vehicle name — from columns 8-19 of JDC
3	ALPHA G ZERO — Right ascension of Greenwich meridian at $0^h.0$ of day of epoch

```
$INPUT
  TYPE = 1.,
  STVEC = 4.1136013,33.359341,121.93431,150.92382,6450.0167,6.28380435,
  TIME = 65.,2.,23.,14.,5.,40.,
  CATI  = 7*1.,
  BNDS  = 1.,1.,.2,.5,1.00584,.100584,.12766061E-2,
  NITER = 10.,
  DELTT = .016666,.416666,
  DRAG = .15667058E-2,
  ZONAL = 0.,0.,0.,0.,
  SECT = 0.,0.,0.,
  NDAYS = 0.,
  CKRMS = 100.,
  COM(32) = .016666,
  COM3(61)=0.016666,
$END
```

Figure 2-3. Sample NAMELIST Input Listing

ORBIT DETERMINATION PROGRAM - NRTPOD

VEHICLE NO. VEHICLE NAME 801 APL M

ALPHA G ZERO
261.093426

INITIAL CONDITIONS

YEAR	MONTH	DAY	HOUR	MINUTE	SECOND
65	6	13	14	0	5.750

X	Y	Z	XDOT	YDOT	ZDOT
4.6880447E 03	2.8020944E 03	4.7494121E 03	-4.1414466E 00	-2.5755530E 00	5.6245785E 00

ALPHA	DELTA	BETA	AZIMUTH	R	V
3.0867211E 01	4.1010048E 01	8.9916624E 01	3.5933168E 02	7.2378457E 03	7.4448699E 00

NO RADIATION PRESSURE

SENSOR LOCATIONS

ID	LATITUDE	LONGITUDE	ALT	R BIAS	A BIAS	E BIAS	R. BIAS	TIME BIAS
28	42.5059	-71.2352	58.	0.	0.	0.	0.	0.
29	42.6459	-71.0934	133.	0.	0.	0.	0.	0.
30	42.6173	-71.4915	154.	0.	0.	0.	0.	0.

Figure 2-4. Sample Run Header

Line No.	Line Description
4	Numerical value of Alpha G Zero, in degrees
5	INITIAL CONDITIONS
6, 7	Epoch time of the run
7, 8	Initial conditions in geocentric inertial Cartesian coordinates; units are km and km/sec
8, 9	Initial conditions in geocentric inertial polar spherical coordinates; units are degrees, km and km/sec.
10, 11	If drag is input, the numerical value of $C_D A/m$ in m^2/kg.
12, 13	If radiation pressure is input, the numerical value of $\gamma A/m$ in m^2/kg.
15-	Sensor information: For each sensor in the input deck the following information is printed: a) Station ID b) North geodetic latitude; ϕ,* degrees c) East longitude; λ, degrees d) Altitude above ellipsoid; h, meters e) Range bias; R_b, km f) Azimuth bias; A_b, degrees g) Elevation bias; E_b, degrees h) Range-rate bias; $\dot{R}_b$, km/sec i) Time bias; T_b, seconds

2.3.3 Observations

This page, and any subsequent ones, lists the chronologically ordered observations for this run. If epoch precedes the observations, the listing begins with the observation nearest epoch and proceeds forward in time. If epoch is past the observations, the listing begins with the observation nearest epoch and proceeds backward in time. And, if epoch is in the middle of the data span, the listing begins with the observation nearest epoch and preceeding it, and proceeding backwards; after the last observation before epoch is listed, the program goes back to epoch, and lists the observations ahead of epoch, beginning with the nearest to epoch. Figure 2-5 shows a sample observation page listing. The columns symbols and their descriptions are:

								OBSERVATION TYPE			
IO	T-TO	YR	MN	DY	HR	MIN	SECS	RANGE SIGMA R	AZ SIGMA A	EL SIGMA E	R DOT SIGMA R.
28	-0.096	65	6	13	14	0	-0.	1231.	260.1472	41.0589	-1.0467
								10.000E-03	5.000E-04	5.000E-04	10.000E-05
29	-0.096	65	6	13	14	0	-0.	1242.	259.3304	40.4985	-1.1341
								10.000E-03	5.000E-04	5.000E-04	10.000E-05
30	-0.096	65	6	13	14	0	-0.	1217.	258.8477	41.7919	-1.1289
								10.000E-03	5.000E-04	5.000E-04	10.000E-05
28	-0.596	65	6	13	13	59	30.000	1279.	247.5210	38.6031	-2.1339
								10.000E-03	5.000E-04	5.000E-04	10.000E-05
29	-0.596	65	6	13	13	59	30.000	1292.	246.9875	37.9879	-2.2044
								10.000E-03	5.000E-04	5.000E-04	10.000E-05
30	-0.596	65	6	13	13	59	30.000	1268.	246.0685	39.1378	-2.2212
								10.000E-03	5.000E-04	5.000E-04	10.000E-05
28	-1.096	65	6	13	13	59	-0.	1357.	236.9802	35.1072	-3.0709
								10.000E-03	5.000E-04	5.000E-04	10.000E-05
29	-1.096	65	6	13	13	59	-0.	1372.	236.6938	34.5037	-3.1236
								10.000E-03	5.000E-04	5.000E-04	10.000E-05
30	-1.096	65	6	13	13	59	-0.	1349.	235.5268	35.4590	-3.1555
								10.000E-03	5.000E-04	5.000E-04	10.000E-05
28	-1.596	65	6	13	13	58	30.000	1462.	228.5556	31.1811	-3.8353
								10.000E-03	5.000E-04	5.000E-04	10.000E-05
29	-1.596	65	6	13	13	58	30.000	1478.	228.4509	30.6270	-3.8725
								10.000E-03	5.000E-04	5.000E-04	10.000E-05
30	-1.596	65	6	13	13	58	30.000	1455.	227.1841	31.3922	-3.9125
								10.000E-03	5.000E-04	5.000E-04	10.000E-05
28	-2.096	65	6	13	13	58	-0.	1586.	221.9139	27.2415	-4.4376
								10.000E-03	5.000E-04	5.000E-04	10.000E-05
29	-2.096	65	6	13	13	58	-0.	1603.	221.9315	26.7499	-4.4526
								10.000E-03	5.000E-04	5.000E-04	10.000E-05
30	-2.096	65	6	13	13	58	-0.	1582.	220.6532	27.3553	-4.5053
								10.000E-03	5.000E-04	5.000E-04	10.000E-05
28	-2.596	65	6	13	13	57	30.000	1726.	216.6576	23.5060	-4.9032
								10.000E-03	5.000E-04	5.000E-04	10.000E-05
29	-2.596	65	6	13	13	57	30.000	1744.	216.7543	23.0756	-4.9193
								10.000E-03	5.000E-04	5.000E-04	10.000E-05
30	-2.596	65	6	13	13	57	30.000	1724.	215.5092	23.5560	-4.9414
								10.000E-03	5.000E-04	5.000E-04	10.000E-05
28	-3.096	65	6	13	13	57	-0.	1879.	212.4470	20.0590	-5.2505
								10.000E-03	5.000E-04	5.000E-04	10.000E-05

Figure 2-5. Sample Observations Print

Column Symbol	Description
ID	Observing station's identification
T-TO	Time of the observation in minutes from epoch (TO)
YR MN DY HR MIN SECS	Greenwich time at which the observation was made. Year, month, day, hour, minutes, and decimal seconds.
RANGE SIGMA R	Range observation, in kilometers Standard deviation of range, in kilometers
AZ SIGMA A	Azimuth observation in degrees, from north Standard deviation of azimuth, in degrees
EL SIGMA E	Elevation observation, in degrees, from horizon Standard deviation of elevation, in degrees
R DOT SIGMA R.	Range rate observation, in kilometers/second Standard deviation of range rate, in kilometers/second

2.3.4 Residuals

The residuals are defined as the difference between the measured observations and the computed observations: $0_m - 0_c = \Delta =$ residual. The computed observations are based on the input initial conditions for the first iteration, and on the improved initial conditions on succeeding iterations. The residuals are chronologically sorted and are listed in the same order as the observations, and correspond exactly in time with their associated measured observations. Figure 2-6 shows a sample residuals print page. The column symbols and their descriptions are as follows:

Column Symbol	Description
ID	Observing station's identification
TIME	Time in minutes from epoch
N	Serial number assigned to each residual for identification purposes. It is constant through the run.

RESIDUALS PRINT

ID	TIME (MIN)	N	R (KM)	A (DEG)	E (DEG)	RDOT (KM/SEC)	J (KM)	V (KM)	W (KM)	VM (KM)	BETA (DEG)
28	-0.096	1	1.47243	0.03	-0.11	-0.000466	-0.4848	-0.2205	2.8116	2.8516	0.022
29	-0.096	5	1.47036	0.04	-0.11	-0.000358	-0.4874	-0.2206	2.7927	2.8435	0.022
30	-0.096	9	1.44148	0.04	-0.11	-0.000344	-0.4852	-0.2213	2.8124	2.8525	0.022
28	-0.596	13	1.45425	0.07	-0.10	0.001442	-0.4953	-0.1811	2.8929	2.9406	0.023
29	-0.596	17	1.45379	0.07	-0.10	0.001510	-0.4945	-0.1820	2.8759	2.9238	0.023
30	-0.596	21	1.41506	0.07	-0.10	0.001551	-0.5005	-0.1811	2.8921	2.9405	0.023
28	-1.096	25	1.38424	0.09	-0.09	0.002838	-0.5134	-0.1424	2.9723	3.0197	0.024
29	-1.096	29	1.38645	0.09	-0.08	0.002852	-0.5096	-0.1450	2.9558	3.0039	0.023
30	-1.096	33	1.35686	0.09	-0.09	0.002908	-0.5041	-0.1465	2.9750	3.0220	0.024
28	-1.596	37	1.29273	0.10	-0.07	0.003665	-0.5258	-0.1092	3.0541	3.1010	0.024
29	-1.596	41	1.29418	0.10	-0.07	0.003657	-0.5232	-0.1104	3.0398	3.0865	0.024
30	-1.596	45	1.25868	0.10	-0.07	0.003693	-0.5236	-0.1121	3.0583	3.1048	0.024
28	-2.096	49	1.17468	0.10	-0.06	0.004062	-0.5470	-0.0711	3.1293	3.1776	0.025
29	-2.096	53	1.17346	0.10	-0.06	0.004029	-0.5445	-0.0702	3.1112	3.1592	0.025
30	-2.096	57	1.13575	0.10	-0.06	0.004052	-0.5481	-0.0724	3.1304	3.1789	0.025
28	-2.596	61	1.05247	0.10	-0.05	0.004169	-0.5712	-0.0376	3.2030	3.2537	0.025
29	-2.596	65	1.05497	0.10	-0.05	0.004132	-0.5702	-0.0417	3.1852	3.2361	0.025
30	-2.596	69	1.01792	0.10	-0.05	0.004130	-0.5682	-0.0394	3.2063	3.2565	0.025
28	-3.096	73	0.93410	0.09	-0.04	0.004099	-0.5984	-0.0095	3.2755	3.3298	0.026
29	-3.096	77	0.92771	0.09	-0.04	0.004071	-0.5996	-0.0051	3.2512	3.3060	0.025
30	-3.096	81	0.89770	0.09	-0.04	0.004058	-0.5959	-0.0099	3.2764	3.3303	0.026
28	-3.596	85	0.80821	0.09	-0.04	0.003957	-0.6329	0.0262	3.3401	3.3996	0.026
29	-3.596	89	0.81228	0.09	-0.04	0.003927	-0.6303	0.0238	3.3217	3.3811	0.026
30	-3.596	93	0.77146	0.09	-0.03	0.003900	-0.6339	0.0259	3.3399	3.3996	0.026
28	-4.096	97	0.69870	0.09	-0.03	0.003772	-0.6545	0.0521	3.4059	3.4715	0.027
29	-4.096	101	0.69378	0.08	-0.03	0.003746	-0.6678	0.0565	3.3837	3.4494	0.027
30	-4.096	105	0.66624	0.09	-0.03	0.003717	-0.6638	0.0497	3.4071	3.4715	0.027
28	-4.596	109	0.58320	0.08	-0.03	0.003579	-0.7047	0.0845	3.4622	3.5341	0.027
29	-4.596	113	0.58567	0.08	-0.03	0.003563	-0.7041	0.0843	3.4435	3.5158	0.027
30	-4.596	117	0.55607	0.08	-0.03	0.003527	-0.7020	0.0799	3.4665	3.5377	0.027
28	-5.096	121	0.48512	0.08	-0.03	0.003390	-0.7418	0.1083	3.5283	3.6071	0.028
29	-5.096	125	0.48828	0.08	-0.03	0.003373	-0.7458	0.1037	3.5042	3.5842	0.028
30	-5.096	129	0.45518	0.08	-0.02	0.003333	-0.7431	0.1045	3.5251	3.6041	0.028
28	-5.596	133	0.38483	0.07	-0.02	0.003211	-0.7880	0.1320	3.5803	3.6684	0.028
29	-5.596	137	0.38561	0.07	-0.02	0.003198	-0.7932	0.1299	3.5542	3.6440	0.028

Figure 2-6. Sample Residuals Print

Column Symbol	Description
R (KM)	Range residual in kilometers
A (DEG)	Azimuth residual in degrees
E (DEG)	Elevation residual in degrees
RDOT (KM/SEC)	Range rate residual in kilometers/second
U (KM)	Up component of the position residual, collinear with and positive in the same direction as the radius vector, in kilometers.
V (KM)	Down component of the position residual, orthogonal to the radius vector, positive in the direction of motion and in the orbit plane, in kilometers.
W (KM)	Cross component of the position residual, normal to the orbit plane and positive in the direction of the angular momentum vector to complete a right-handed coordinate system, in kilometers.
VM (KM)	Magnitude of the position residual or displacement vector, in kilometers.
BETA (DEG)	Residual angle between the measured positive vector and the computed orbit plane, in degrees.

The numerical values for the residuals are listed in the above columns on one or more pages. A symbol or letter following a numerical value indicates that the residual has been deleted from further inclusion in the differential correction by a specified criterion, which are the following:

Symbol	Criterion
*	Observation deleted by DELETE card (analyst selected)
N	Observation deleted as a gross outlier; if $\Delta > N\sigma$, observation is deleted, where N is some large number, nominally 1000.
K	Observation deleted from this iteration (other than first) by KRMS test.
S	Observation deleted because weight is zero. (called by setting σ to zero)

A fifth type of deletion, DTMAX, (See Preliminary Data input, Section 2. 2. 3) rejects observations which are a specified number of days from epoch (nominally, 20 days). If an observation is deleted by this criterion, it's residual is not printed (nor computed) in the residuals page.

2. 3. 5 Mean and Standard Deviations by Sensor

To aid the analyst in determining where systematic error solution is required, or in deleting data, estimates of standard deviations by sensor and type are printed. This information is listed immediately following the residuals print; Figure 2-7 is a sample output. A given station's data are arranged into columns of three lines each.

The column symbols and their descriptions are:

Column Symbol	Description
ST. ID.	Observing station's identification
R	Numerical values associated with range, in kilometers
A	Numerical values associated with azimuth, in degrees
E	Numerical values associated with elevation, in degrees
RDOT	Numerical values associated with large rate, in kilometers/second.

The last column on the right identifies the data on each line as follows:

MEAN	The arithmetic mean or average values of the residuals for each type of data observed by the given station.
RMS	The estimated standard deviation (one sigma) for each type of data observed by the given station.
NA/NR	The number of observations accepted/the number of observations rejected, for each type of data observed by the given station.

2. 3. 6 Iteration Summary

This page shows the results and convergence status for a given iteration. If the solution is not converging, the normal and variance-

MEAN AND RMS BY STATION AND TYPE

ST. ID.	R	A	E	RDOT	
28	0.827188E 00	0.186581E-01	-0.537455E-01	-0.506442E-03	MEAN
	0.453326E-00	0.739124E-01	0.310753E-01	0.431971E-02	RMS
	23./ -0.	23./ -0.	23./ -0.	23./ -0.	NA/NR
29	0.832364E 00	0.187048E-01	-0.532505E-01	-0.503191E-03	MEAN
	0.451489E-00	0.725810E-01	0.304283E-01	0.431123E-02	RMS
	23./ -0.	23./ -0.	23./ -0.	23./ -0.	NA/NR
30	0.800144E 00	0.190631E-01	-0.539359E-01	-0.489275E-03	MEAN
	0.448891E-00	0.753115E-01	0.317984E-01	0.428740E-02	RMS
	23./ -0.	23./ -0.	23./ -0.	23./ -0.	NA/NR

Figure 2-7. Sample Output of Sensor Performance

covariance matrices are not printed on the iteration summary page. The first line on the page identifies the iteration number. Figure 2-8 is a sample iteration summary printout. The following describes the tabulated solution vector data, arranged in columns as shown below:

Column Symbol	Description
CATEGORY 1 VARIABLES	These are the orbital and drag parameters, identified by a number and a name as follows:
1 ALPHA	Right ascension (degrees)
2 DELTA	Declination (degrees)
3 BETA	Flight path angle from local vertical (degrees)
4 AZ	Azimuth to inertial velocity vector, clockwise from true north (degrees)
5 R	Radius vector from geocenter (kilometers)
6 V	Velocity vector magnitude (kilometers/sec)
7 DRAG	Drag parameter (meters^2/kilogram)
DELTA	The corrections applied by the program to each variable
OLD	Numerical values for the variables from the previous iteration
NEW	Numerical values for the variables for this iteration (NEW = OLD + DELTA)
SIGMA	The uncertainty in each variable, computed from the variance-covariance matrix
BOUNDS	The constraints applied to the changes which the program is allowed to make to the solution variables.

If category 2 variables (station and data biases) are being solved for, a tabulation much like that just described will be listed next. The columns are as follows:

ITERATION NUMBER 7

CATEGORY 1 VARIABLES		DELTA	OLD	NEW	SIGMA	BOUNDS
1	ALPHA	0.40808989E-03	0.41155428E 01	0.41159509E 01	0.20954771E-02	0.39999998E 01
2	DELTA	-0.42437790E-03	0.33348570E 02	0.33343145E 02	0.84676772E-03	0.39999998E 01
3	BETA	0.36002329E-01	0.12306846E 03	0.12310446E 03	0.23862186E-01	0.79999998E 00
4	AZ	0.12180633E-01	0.15086272E 03	0.15087491E 03	0.17051763E-00	0.19999999E 01
5	R	0.88191282E-01	0.64519928E 04	0.64520810E 04	0.34612728E-01	0.40233598E 01
6	V	-0.23335247E-03	0.62708183E 01	0.62705854E 01	0.92077111E-03	0.40233599E-00
7	DRAG	0.12048458E-04	0.17144214E-02	0.17264699E-02	0.88960422E-05	0.51064242E-02

SOLUTION IS CONVERGING

SOLUTION IS NOT AFFECTED BY BOUNDS

CURRENT RMS	3.689284
PREDICTED RMS	3.652123
BEST RMS	3.689284

NORMAL MATRIX - ATA

	1	2	3	4	5	6
1	0.52723554E 10					
2	-0.13372599E 11	0.33932368E 11				
3	-0.32450361E 08	0.82322752E 08	0.77837010E 06			
4	0.73764916E 07	-0.18781980E 08	-0.77147566E 05	0.14080855E 05		
5	-0.57492154E 08	0.14588019E 09	-0.10263968E 06	-0.53599537E 05	0.99157370E 06	
6	0.12309331E 10	-0.31230327E 10	-0.10293188E 08	0.21883492E 07	-0.10872594E 08	0.36011195E 09
7	-0.11930114E 12	0.30266629E 12	0.25626687E 10	-0.27552571E 09	-0.15537734E 09	-0.38007107E 11

	7
7	0.85382630E 13

ATA INVERSE

	1	2	3	4	5	6
1	0.43910248E-05					
2	0.17078749E-05	0.71701559E-06				
3	0.11086942E-04	0.20626362E-05	0.56940392E-03			
4	0.33839763E-03	0.13362370E-03	0.83482247E-03	0.29076263E-01		
5	0.33801194E-05	-0.66119180E-05	0.32895802E-03	-0.39879881E-04	0.11980409E-02	
6	-0.17765208E-05	-0.67750461E-06	-0.90614553E-05	-0.15144019E-03	-0.30405156E-05	0.84781945E-06

Figure 2-8. Sample Iteration Summary Print (NRTPOD)

Column Symbol	Description
CATEGORY 2 VARIABLES	These variables are numbered from the next digit following the last category 1 variable number to 25. Each number will be followed by the station ID, as used in the SENSOR LOCATIONS, and the name of the variable can be any of the following:

RBIAS	Range (kilometers)
AZBIAS	Azimuth (degrees)
EBIAS	Elevation (degrees)
RDBIAS	Range rate (kilometers/sec)
TBIAS	Time (seconds)
LTBIAS	Station north latitude (degrees)
LNBIAS	Station east longitude (degrees)
HBIAS	Station altitude (meters)

DELTA OLD NEW SIGMA BOUNDS	Same as for Category 1 variables

The following line states "SOLUTION IS (IS NOT) CONVERGING." The solution is converging if the current RMS of the residuals is smaller than the best RMS to this point in the run.

This message is followed by "SOLUTION IS (IS NOT) AFFECTED BY BOUNDS." The program first forms an unbounded solution, and if it satisfies the condition $\sum \left(\frac{\text{DELTA}_i}{\text{BOUNDS}_i} \right)^2 \leq 1$, "SOLUTION IS NOT AFFECTED BY BOUNDS" is printed. If the above condition is not satisfied, the normal equations are solved until the constraint is satisfied, and "SOLUTION IS AFFECTED BY BOUNDS" is printed.

Next are printed the current RMS (Root Mean Square of Weighted Residuals), the predicted RMS, and the best RMS so far in the curve fit. If the solution is converging, the normal matrix (A^TA) and the inverse of the normal matrix, the variance-covariance matrix are printed.

The next message will appear on the final iteration only, and will be one of the following:

SOLUTION HAS CONVERGED

MAXIMUM ITERATIONS EXCEEDED

BOUNDS/8 FAILED

This indicates the criterion on which the run is terminated.

2.3.7 Trajectory Print

The last page(s) of the run consist of blocks of trajectory and related data, updated to times referenced to epoch which were specified by input. Figure 2-9 shows a sample trajectory printout page. The initial conditions for propagating the trajectory are (1) specified by input if it is a trajectory run only, or (2) obtained from the converged differential correction which immediately precedes the trajectory runout.

Preceding the first trajectory block are the secular rates of the right ascension of the ascending node and the argument of perigee (degrees/day) and the anomalistic period (minutes) to order J_2. The first line of each trajectory block contains the Gregorian date and the Greenwich mean time for the data, time in minutes from epoch, and time in days from January 0 of the year of epoch. The following list describes the parameters associated with the symbols in the trajectory block:

Symbol	Description
X Y Z XDOT YDOT ZDOT	Components of the position and velocity vector in geocentric inertial Cartesian coordinates. It is a right-handed orthogonal system where the X axis is in the direction of the vernal equinox and the Z axis is in the direction of true north. Units are kilometers and kilometers/second. Coordinates are true of 0^h 0 day of epoch.
ALFA	Right ascension, in degrees
DLTA	Declination, in degrees
BETA	Flight path angle, in degrees, positive downward from the local vertical

```
START TRAJECTORY
  END TRAJECTORY
                          NODE RATE                              PERIGEE RATE                          ANOMALISTIC PER.
                        0.                                     -0.                                     5.39928505E 01

 23 FEBRUARY  1965  14 HR   5 MIN  40.00 SEC  MINUTES FROM EPOCH        0.          DAYS FROM 0HR JAN   53.587268

   X   0.53757474E 04 XDOT -0.51780354E 00 ALFA  0.41155884E 01   AZ  0.15086265E 03  ALT  0.43377543E 02
   Y   0.38680949E 03 YDOT  0.25281087E 01 DLTA  0.33348437E 02    R  0.64520157E 04  LAT  0.33525372E 02
   Z   0.35468615E 04 ZDOT -0.57153791E 01 BETA  0.12306933E 03    V  0.62709658E 01  LON  0.35944764E 03

 SMA   0.47320792E 04 NODE  0.20115300E 03   UX  0.83318881E 00 RPVX  0.29855584E-00 ALAT  0.14300449E 03
 ECC   0.62490337E 00  OMG  0.29524426E 03   UY  0.59951571E-01 RPVY  0.34974895E-00  TAU  0.16552278E 02
 INC   0.66000260E 02    M  0.26356046E 03   UZ  0.54972920E 00 RPVZ -0.49064410E-00  PRD  0.53992849E 02
 1/A   0.13478567E 01    D -0.43785325E-00 APOG  0.70789065E 03  PRG -0.24855391E 04            ELLIPSE

 23 FEBRUARY  1965  14 HR   5 MIN  41.00 SEC  MINUTES FROM EPOCH        0.01666   DAYS FROM 0HR JAN   53.587280

   X   0.53752258E 04 XDOT -0.52571724E 00 ALFA  0.41427833E 01   AZ  0.15387707E 03  ALT  0.41521529E 02
   Y   0.38933556E 03 YDOT  0.25272371E 01 DLTA  0.33307662E 02    R  0.64485925E 04  LAT  0.33484491E 02
   Z   0.35411453E 04 ZDOT -0.57198507E 01 BETA  0.12309582E 03    V  0.62753484E 01  LON  0.35947067E 03

 SMA   0.47314834E 04 NODE  0.20115334E 03   UX  0.83355024E 00 RPVX  0.29805756E-00 ALAT  0.14305104E 03
 ECC   0.62497690E 00  OMG  0.29525563E 03   UY  0.60375278E-01 RPVY  0.34967457E-00  TAU  0.16533954E 02
 INC   0.65999846E 02    M  0.26365452E 03   UZ  0.54913459E 00 RPVZ -0.49087722E-00  PRD  0.53982651E 02
 1/A   0.13480265E 01    D -0.43823764E-00 APOG  0.70755196E 03  PRG -0.24858259E 04            ELLIPSE

 23 FEBRUARY  1965  14 HR   5 MIN  42.00 SEC  MINUTES FROM EPOCH        0.03333   DAYS FROM 0HR JAN   53.587291

   X   0.53746961E 04 XDOT -0.53359356E 00 ALFA  0.41699831E 01   AZ  0.15689111E 03  ALT  0.39662538E 02
   Y   0.39186218E 03 YDOT  0.25261484E 01 DLTA  0.33266839E 02    R  0.64451636E 04  LAT  0.33443559E 02
   Z   0.35354236E 04 ZDOT -0.57237533E 01 BETA  0.12312219E 03    V  0.62791323E 01  LON  0.35949369E 03

 SMA   0.47304577E 04 NODE  0.20115392E 03   UX  0.83391151E 00 RPVX  0.29752872E-00 ALAT  0.14309752E 03
 ECC   0.62509465E 00  OMG  0.29527520E 03   UY  0.61799414E-01 RPVY  0.34957012E-00  TAU  0.16514434E 02
 INC   0.65999134E 02    M  0.26372634E 03   UZ  0.54853898E 00 RPVZ -0.49106134E-00  PRD  0.53965098E 02
 1/A   0.13483188E 01    D -0.43857908E-00 APOG  0.70695277E 03  PRG -0.24863343E 04            ELLIPSE

 23 FEBRUARY  1965  14 HR   5 MIN  43.00 SEC  MINUTES FROM EPOCH        0.04999   DAYS FROM 0HR JAN   53.587303
```

Figure 2-9. Sample Trajectory Printout

Symbol	Description
AZ	Azimuth of the velocity vector, in degrees, positive clockwise from true north.
R	Magnitude of radius vector from the geocenter, in kilometers
V	Magnitude of velocity vector, in kilometers/second
ALT	Height of the satellite above mean sea level, in nautical miles.
LAT	Geodetic north latitude of the satellite, in degrees.
LON	East longitude of the satellite, in degrees.
SMA	Semi-major axis, in kilometers.
ECC	Eccentricity of the orbit.
INC	Inclination of the orbit plane to the equator, in degrees, positive counterclockwise from the equatorial to the orbit plane at the ascending node.
NODE	Right ascension of the ascending node, in degrees.
OMG	Argument of perigee, in degrees, positive in the direction of motion from the ascending node.
M	Mean anomaly, in degrees, positive in the direction of motion from perigee.
UX UY UZ	Direction cosines of the position in Cartesian coordinates with axes directed as in the XYZ system previously described.
RPVX RPVY RPVZ	Components in Cartesian coordinates of a vector in the orbit plane which is orthogonal to the position ($\underline{r}$) and angular momentum ($\underline{h}$) vectors.
ALAT	Argument of latitude, in degrees, equals the sum of the argument of perigee and the true anomaly.
TAU	Time until the next ascending nodal crossing, in minutes from epoch.
PRD	Osculating period of the orbit, in minutes.
1/A	Inverse of the semi-major axis, in earth-radii (Indeterminacy-free element).
D	Indeterminacy-free element = $\frac{R \cdot \dot{R}}{\sqrt{\mu}}$, in (earth-radii) $^{1/2}$.

Symbol	Description
APOG	Altitude of apogee above a mean equator, in nautical miles.
PRG	Altitude of perigee above a mean equator, in nautical miles.
ELLIPSE HYPERBOLA	Prints one or the other to describe the conic's form. If HYPERBOLA, many of the preceding values will be omitted.

The above parameters are repeated for as many updates as were requested in the input.

2.3.8 Matrix Update

In addition to the block of data printed for each trajectory update time, as described above, a normal matrix and an error matrix can be updated and printed at each print time. As in the case for the trajectory update only, the initial conditions (the matrix at t = 0 = epoch) are obtained from (1) input, if it is a trajectory and update only; or (2), from the matrix computed in the differential correction which precedes the trajectory and update. The symmetric error matrix is called the "sigma and rho" matrix and is derived from the covariance matrix; the diagonal terms are the estimated standard deviations (σ) and the off diagonal terms are the correlation coefficients (ρ). The normal matrix is the inverse of the covariance matrix and is obtained in this way; hence, it is necessary to input two matrices when a matrix update is required. See Figure 2-10 for a sample print of a trajectory propagation and a matrix update. The matrices are in polar spherical (ADBARV) coordinates and the following list describes the parameters given in the columns (and rows) of both the "sigma and rho" matrix and the normal matrix:

Column Symbol	Description
1	α, right ascension (degrees)
2	δ, declination (degrees)
3	β, flight path angle (degrees)
4	A, azimuth of velocity vector (degrees)
5	R, radius vector magnitude (kilometers)

```
START TRAJECTORY
  END TRAJECTORY
                NODE RATE                     PERIGEE RATE                  ANOMALISTIC PER.
             -5.4954716E-02                  -3.1346241E 00                  1.0297719E 02

13    JUNE    1965  14 HR    0 MIN    5.75 SEC  MINUTES FROM EPOCH        0.        DAYS FROM OHR JAN 164.593333

   X  0.46892976E 04 XDOT -0.41416187E 01 ALFA  0.30838015E 02   AZ  0.35933468E 03  ALT  0.45990496E 03
   Y  0.27996011E 04 YDOT -0.25732827E 01 DLTA  0.41007957E 02    R  0.72373490E 04  LAT  0.41198586E 02
   Z  0.47488872E 04 ZDOT  0.56235224E 01 BETA  0.89914879E 02    V  0.74430366E 01  LON  0.27914562E 03

 SMA  0.72800339E 04 NODE  0.31274581E 02   UX  0.64793036E 00 RPVX -0.59550016E 00 ALAT  0.41009883E 02
 ECC  0.60486922E-02  OMG  0.26706898E 02   UY  0.38682690E-00 RPVY -0.36997298E-00  TAJ  0.91420656E 02
 INC  0.90502054E 02    M  0.14132491E 02   UZ  0.65616398E 00 RPVZ  0.80613715E 00  PRD  0.10302873E 03
 1/A  0.87611748E 00    D  0.15871491E-02 APOG  0.51074708E 03  PRG  0.46319345E 03              ELLIPSE

           SIGMA AND RHO MATRIX POLAR SPHERICAL COORDINATES

             1               2               3               4               5               6
  1  0.22662769E-03
  2 -0.98242734E 00  0.66418796E-03
  3 -0.16399785E-00  0.12356485E-00  0.86739340E-04
  4 -0.98205810E 00  0.99979854E 00  0.11872393E-00  0.51906194E-02
  5 -0.38531018E-00  0.27161105E-00  0.48537928E-00  0.27002066E-03  0.22073608E-01
  6 -0.81113520E 00  0.72667783E 00  0.38248625E-00  0.72534650E 00  0.83595742E 00  0.58540381E-04

           NORMAL MATRIX POLAR SPHERICAL COORDINATES

             1               2               3               4               5               6
  1  0.16519017E 10
  2  0.29237192E 09  0.61412035E 10
  3 -0.27064874E 08 -0.26745674E 09  0.18789719E 09
  4  0.11269175E 08 -0.77073827E 09  0.32297987E 08  0.98530937E 08
  5 -0.36966406E 07  0.13361031E 07 -0.63181818E 06 -0.17096698E 05  0.45360520E 05
  6  0.32338734E 10 -0.41498806E 09  0.13580288E 09  0.88608761E 08 -0.25585371E 08  0.16156782E 11
```

Figure 2-10. Sample Output of Trajectory and Matrix Update

Column Symbol	Description
6	V, velocity vector magnitude (kilometers/sec)
7	C_DA/m, magnitude of drag parameter (meters ^{2}/kg)

The updated matrices are either 6x6 or, if drag was a solution variable, 7x7.

2.4 MAGNETIC TAPES

2.4.1 NRTPOD Trajectory Tape (TAPE TTRJTP)

Due to the complexity of the NRTPOD program and the limited core space, the trajectory simulator segment of NRTPOD is overlayed by the differential correction and print-update segments. The trajectory data are transmitted between trajectory and differential correction and between trajectory and print-update through the trajectory tape.

The trajectory tape is in the FORTRAN binary mode, composed of a variable number of 59-word logical data records, terminated with a 59-word sentinel end-of-file record composed of the same floating point number in each word. Following the sentinel record is an end-of-file mark. Each word of data is in normalized floating point form.

Each record on tape corresponds to either an observation timer (if the tape is being generated for the differential correction segment) or a timer from the DELTT array (if the tape is being generated for the print-update segment). Each data record is composed of the following information:

Word 1	Time (minutes from 0 hours day of epoch)
Word 2	Impact flag. If non-zero, the vehicle has impacted the earth.
Word 3-5	x, y, z... the geocentric coordinates of the spacecraft in earth radii.
Word 6-8	$\dot{x}$, $\dot{y}$, $\dot{z}$... the geocentric velocity of the spacecraft in earth radii/minute.
Word 9-11	$\ddot{x}$, $\ddot{y}$, $\ddot{z}$... the geocentric acceleration of the spacecraft in earth radii/minute squared.

Words 12 - 59 are reserved for the $\frac{\partial(x, y, z, \dot{x}, \dot{y}, \dot{z})}{\partial(\text{CAT1 variable})}$, the partial derivatives of the current position and velocity of the spacecraft with respect to the CAT1 variable. Partials will appear corresponding to each non-zero entry in the CAT1 array.

Words 12 - 17 $\frac{\partial x}{\partial p_1}, \frac{\partial y}{\partial p_1}, \frac{\partial z}{\partial p_1}, \frac{\partial \dot{x}}{\partial p_1}, \frac{\partial \dot{y}}{\partial p_1}, \frac{\partial \dot{z}}{\partial p_1},$

Words 18 - 23 $\frac{\partial x}{\partial p_2}, \frac{\partial y}{\partial p_2}, \frac{\partial z}{\partial p_2},$ —, —, —,

Words 54 - 59 $\frac{\partial x}{\partial p_8}, \frac{\partial y}{\partial p_8}, \frac{\partial z}{\partial p_8},$ —, —, $\frac{\partial \dot{z}}{\partial p_8}.$

If only three non-zero entries appear in the CAT1 array, only words 12 - 29 will be used for the partials, and words 30 - 59 will be 0. The partial derivatives are in units of earth radii, radians and minutes for α, δ, p, A, R, V and units of feet, squared/slug for $\frac{C_d A}{m}$.

2.4.2 NRTPOD Observation Tape (TAPE MT)

The NRTPOD observation tape is a FORTRAN binary tape generated from the observation cards presented on input. The observational data are placed on tape time sorted about the NRTPOD epoch. Any pre-epoch data will occur first on tape, in descending time order from epoch. Following any pre-epoch data will be the post-epoch observation in ascending time order.

Each logical record on the observation tape is 253 words. The final data record is a sentinel end-of-file record composed of 253 words of the same piece of data. Following the sentinel end-of-file is an end-of-file mark. All of the observation data is contained in the first file.

A typical record on the observation tape will appear as:

Word i ... station ID (BCD)
Word i + 1 ... time of observation (minutes from 0 hours epoch day)

Word i + 2 ...	Range (earth radii)
Word i + 3 ...	Azimuth (radius)
Word i + 4 ...	Elevation (radius)
Word i + 5 ...	Range rate (earth radii/minute)
Word i + 6 ...	Not used
Word i + 7 ...	σ Range (earth radii)
Word i + 8 ...	σ Azimuth (radians)
Word i + 9 ...	σ Elevation (radians)
Word i + 10...	σ Range Rate (earth radii/minute)
Word i + 11...	Station ID

Each record is composed of 23 observations. If the final data record does not contain exactly 23 observations, it will be filled out with floating point zeros. All data except the station ID's are in normalized floating point format.

2.5 NRTPOD STORAGE MAP

2.5.1 COMMON/EPHCOM/ECOM (190)
The lunar-solar ephemeris data

Name	Equivalence	Dimension	Description
XJD	1	10	Julian Date - 2430000. for each day of lunar-solar ephemeris data.
POS	11	10, 3, 2	A triply subscripted array for the Cartesian position of the moon and sun relative to the earth in earth radii measured with respect to the true equator and equinox of 0 hours, day of epoch. The first subscript denotes the day ...; the second subscript denotes x, y, or z ...; the third subscript is 1 for moon, 2 for sun.
DEL2	71	10, 3, 2	A triply subscripted array for the second central differences of the coordinates defined in POS.
DEL4	131	10, 3, 2	A triply subscripted array for the fourth central differences of the coordinates defined in POS.

2.5.2 COMMON/VSTR/VSTR (2700)

The variable storage block for NRTPOD containing arrays and vectors whose length is a function of the input solution vector or the number of stations used during the fit. The location of the first cell of each vector or array is listed in //BLK2.

2.5.3 COMMON/TEMP/TEMP(59)

A block of temporary storage for use by any NRTPOD subroutine.

2.5.4 COMMON/TRJCOM/TRJ (60)

The following COMMON block is used to transmit information between subroutines.

Name	Equivalence	Dimension	Description
COLA	1	1	Cos λ, where λ = the vehicle longitude at the current integration time in TLIST (2)
SILA	2	1	Sin λ
COPH	3	1	Cos ϕ, where ϕ is the geocentric latitude of the vehicle at the current integration time, TLIST(2)
SIPH	4	1	Sin ϕ
CSALF	5	1	Cos x, where x is the right ascension of the vehicle at the current integration time, TLIST(2)
SNALF	6	1	Sin x
TMINUS	7	1	A flag to indicate to subroutine SELECT the direction of integration. When the first pre-epoch time is processed, TMINUS is set = 1. When the first post-epoch integration strip is taken, the integration list is initialized if TMINUS is = 1.
TR	8	1	Magnitude of vehicle positive relative to geocenter, in earth radii.
TR2	9	1	Square of TR
TR3	10	1	Cube of TR
TR5	11	1	Fifth power of TR
TR7	12	1	Seventh power of TR
TV	13	3	The Cartesian velocity components $\dot{x}$, $\dot{y}$, $\dot{z}$ of the spacecraft relative to a rotating earth in earth radii/minute.
TVA	16	1	The magnitude of the vector TV.
FLVE	17	1	Flag set by TRAJ to indicate whether the variational

Name	Equivalence	Dimension	Description
			equations need be evaluated. On predictor steps FLVE is set = 1 to indicate evaluation, on corrector steps FLVE is set = 0.
TPOT	18	3	The perturbative acceleration of the spacecraft due to the earth's potential field, in earth radii/minute squared.
TBPERT	21	3	The perturbative acceleration of the spacecraft due to the sun and moon, in earth radii/minute squared.
TRPRES	24	3	The perturbative acceleration of the spacecraft due to solar radiation pressure, in earth radii/minute squared.
TDRAG	27	3	The perturbative acceleration of the spacecraft due to atmospheric drag, in earth radii/minute squared.
PMAT	30	9	The 3x3 coefficient matrix which pre-multiplies the $\frac{\partial (x, y, z)}{\partial (Pi)}$ position partial derivatives with respect to each CAT1 variable.
VMAT	39	9	The 3x3 coefficient matrix which premultiplies the $\frac{\partial (\dot{x}, \dot{y}, \dot{z})}{\partial (Pi)}$ velocity partial derivatives with respect to each CAT1 variable.
	48-60		Not used.

2. 5. 5 COMMON/PLS/PLS (125)

The following COMMON block is used to transmit data between routines of the partials and least squares segments.

Name	Equivalence	Dimension	Description
PCMR	1	1	The computed slant range of the spacecraft relative to the current station, in PSTAT.

Name	Equivalence	Dimension	Description
PCSA	2	1	Cos A, where A is the computed azimuth of vehicle relative to the current station.
PCSALF	3	1	Cos α, where α is the right ascension of the current station.
PCSE	4	1	Cos E, where E is the elevation of the spacecraft relative to the current station.
PDELFG	5	4	Deletion flags for residuals in PRESDT (1-4). These flags are in BCD. The code is bbbbbb = data accepted Kbbbbb = deleted by K*RMS Sbbbbb = deleted by 0 sigma *bbbbb = deleted by residual # Nbbbbb = deleted by N*SIGMA
	9	1	Not used.
POBCNT	10	1	The number of data points currently accepted in the fit.
PRSUBI	11	1	Auxiliary quantity = the product of PV and PCMR
PSNA	12	1	Sin A, where A is the computed azimuth of the vehicle relative to the current station.
PSNALF	13	1	Sin α, where α is the right ascension of the station.
PSNE	14	1	Sin E, where E is the computed elevation of the spacecraft relative to the current station.
PSTAT	15	12	The working sensor table. The station elements correspond to the current station whose observations are found in PUBS.

Name	Equivalence	Dimension	Description

PSTAT (1) . . . station latitude (radians) ϕ

PSTAT (2) . . . station longitude (radians) λ

PSTAT (3) . . . station altitude (earth radii) h

PSTAT (4) . . . cos ϕ

PSTAT (5) . . . sin ϕ

PSTAT (6) . . . $\alpha_{go} + \lambda$

PSTAT (7) . . . W_1^s

PSTAT (8) . . . W_3^s

PSTAT (9) . . . category 2 variable code word

PSTAT (10-12) . . . not used

Name	Equivalence	Dimension	Description
PUDTI	27	3	The topocentric direction cosines of the velocity vector in earth fixed equatorial system.
PUI	30	3	The topocentric direction cosines of the vehicle position in the equatorial system.
PV	33	1	Auxiliary quantity equal to RSS of PV (1) and PV (2).
PVI	34	3	The topocentric direction cosines of the vehicle position in the horizon system.
PWDTI	37	3	Geocentric earth fixed velocity of the vehicle in a station meridian equatorial system.
PWI	40	3	Geocentric position of the vehicle in a station meridian equatorial system.
PRESDT	43	12	The residual vector:

PRESDT (1) . . . Residual in range

PRESDT (2) . . . Residual in azimuth

PRESDT (3) . . . Residual in elevation

Name	Equivalence	Dimension	Description
	PRESDT (4) ...		Residual in range rate
	PRESDT (5) ...		Component of R, A, E residuals in uprange direction.
	PRESDT (6) ...		Component of R, A, E residual in downrange direction.
	PRESDT (7) ...		Component of R, A, E residual in crossrange direction.
	PRESDT (8) ...		Magnitude of uprange, downrange, and crossrange residual vector.
	PRESDT (9) ...		Angle between computed and observed orbit planes.
	PRESDT (10-12) ...		Not used.
IRCNT	55	4	Residual number of range, azimuth, elevation and range rate respectively.
TSUS	59	1	Current RMS of the residual data.
IPFRST	60	1	First time in flag for RADR. If a-priori A^TA is present, IPFRST is initially -1, if no a priori, IPFRST is 0; after the initial entrance to RADR, IPFRST is 1.
PWPP	61	24	A 3x8 array describing the partial derivatives of PWI with respect to each of the CATI variables.
PWDTPP	85	24	A 3x8 array describing the partial derivative of PWDTI with respect to each of the CATI variables.
	109-125		Not used.

2.5.6 COMMON/INPP/DTMP (300), DATA (1000)

The following COMMON block is used to transmit data between routines of the input processor link.

Name	Equivalence	Dimension	Description
DTMP	1	50	2 cells per station, to identify the CAT2 code words. ID_1, code word $_1$, ID_2, code word $_2$, · · · The code word is of the form I*10+J I = starting location of IVSTR (NPRCD) code words for this station. J = Final location in IVSTR (NPRCD)
DTMP	51	250	A 10x25 block derived from the sensor card data. 10 cells for each station, up to 25 stations maximum. i ... Station ID i+1 ... Range bias (Earth radii) i+2 ... Azimuth bias (Radians) i+3 ... Elevation bias (Radians) i+4 ... Range rate bias (Earth radii/minute) i+5 ... Time bias (minutes) i+6 ... σ Range (Earth radii) i+7 ... σ Azimuth (radians) i+8 ... σ Elevation (radians) i+9 ... σ Range Rate (Earth radii/minute)
DATA	Storage		
CJ	1	12	Values of the zonal harmonic coefficients for the Earth, J_1, J_2, · · ·, J_{12}.
CJNM	13	6, 6	A two-dimensional array with the sectorial harmonic coefficients along the main

Name	Equivalence	Dimension	Description
			diagonal J_{11}, J_{22}, ···, J_{66}; the tesseral harmonics up to order 6 below the main diagonal J_{21}, J_{31}, ···, J_{65} and the corresponding tesseral phase angle λ_{21}, λ_{31}, ···, λ_{65} above the diagonal in degrees.

CJNM (I, I) $= J_{II}$ $I = 1, \cdots, 6$

CJNM (I, J) $= J_{IJ}$ $I, J = 1, 2, \cdots, 6$ $I > J$

CJNM (I, J) $= \lambda_{JI}$ $I, J = 1, 2, \cdots, 6$ $I < J$

Name	Equivalence	Dimension	Description
CLAMNN	49	6	The sectorial phase angles λ_{11}, λ_{22}, ···, λ_{66} in degrees.
ZONAL	55	12	Flags to indicate which zonal harmonics J_1, J_2, ···, J_{12} are to be included in the earth's potential field model. If ZONAL (I) is 0, ignore J_I, if ZONAL (I) $\neq$ 0, include J_I.
SECT	67	6	Flags to indicate which sectorial harmonics J_{11}, J_{22}, ···, J_{66} are to be included in the earths potential field model. A flag is non-zero to indicate inclusion of the harmonic.
TESS	73	15	Code words to indicate the tesseral harmonics to be included in the earths potential field model. If J_{IJ} is desired, TESS (i) = 10*I+J. The first zero entry indicates the end of the list.
STVEC	88	6	The input STVEC parameters ...either x, y, z, $\dot{x}$, $\dot{y}$, $\dot{z}$ or α δ β ARV or λ δ β ARV in kilometers, seconds and degrees.

Name	Equivalence	Dimension	Description
DRAG	94	1	The input value of $\frac{C_d A}{m}$ in meters squared/kilogram.
DRAGCD	95	1	The drag coefficient C_d.
DRAGA	96	1	The effective area of the spacecraft for use in the drag calculation, in meters squared.
DRAGM	97	1	The mass of the spacecraft for use in the drag calculation, in kilograms.
RADPR	98	1	The radiation pressure coefficient $\frac{\gamma A}{m}$, meters squared per kilogram.
RPGAM	99	1	γ for use in radiation pressure calculation.
RPA	100	1	Effective area of spacecraft for use in radiation pressure calculation, meters squared.
RPM	101	1	Effective mass of the spacecraft for use in radiation pressure calculation, kilograms.
SMAT	102	210	Storage for up to a 20x20 upper triangular by rows a-priori $A^T A$ normal matrix in $\alpha \delta \beta$ARV coordinates. Units of degrees, kilometers, and seconds.
CAT1	312	7	Flags, non-zero to indicate which of α, δ, β, A, R, V, $\frac{C_d A}{m}$ are to be included as the solution vector. These are the category 1 variables.
	319		Not used.

Name	Equivalence	Dimension	Description
CAT2	320	225	Storage for the category 2 variable identification. 9 cells per station, up to 25 stations. Storage for each station is:

i ... Station ID

i+2 ... Flag for Range bias (non-zero to include)

i+3 ... Flag for Azimuth bias (non-zero to include)

i+4 ... Flag for Elevation bias (non-zero to include)

i+5 ... Flag for Range Rate bias (non-zero to include)

i+6 ... Flag for Station latitude bias (non-zero to include)

i+7 ... Flag for Station longitude bias (non-zero to include)

i+8 ... Flag for Station height bias (non-zero to include)

BISES	545	50	Storage for the bias estimates of the indicated category 2 variables in the order of the CAT2 array. Up to 50 biases may be specified, in units of kilometers, degrees, seconds.
DELET	595	100	Table of residual deletion numbers. Up to 50 pairs.
BNDS	695	50	The bounds for each parameter in the solution vector in the order of the CAT1, CAT2 arrays, in kilometers, degrees, seconds and meters squared/kilograms.
TPO5	745	10, 3, 2	A triply subscripted array for the Cartesian position of the moon and sun on 10 consecutive days. Subscript one identifies the day, subscript two, the coordinates x, y, z, and subscript three the body, 1 for moon, 2 for sun. Coordinates are in earth radii relative to the mean equator and equinox of 1950.
TDEL2	805	10, 3, 2	The second central difference for TPOS.

Name	Equivalence	Dimension	Description
TDEL4	865	10, 3, 2	The fourth central difference for TPOS.
UPMAT	925	28	Storage for up to a 7x7 lower triangular covariance matrix stored by rows in α, δ, β, A, R, V, $\frac{C_d A}{m}$ in units of degrees, kilometers, seconds, and meters squared/kilogram.
NDTMP	953	1	A pointer used in subroutines SENRD and LODSEN to indicate the next entry in DTMP for sensor bias and σ data.
	954-1000		Not used.

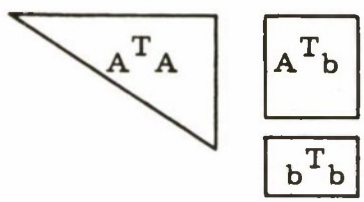
2.5.7 COMMON//BLK 1 (60)

Name	Equivalence	Dimension	Description
CBE	1	1	Semi-minor axis of the earth, earth radii.
CELLIP	2	1	Ellipticity of the earth.
CMU	3	1	GM of earth, earth radii cubed/minute squared.
CWE	4	1	Earth's rotational rate, radians/minute.
CGMR	5	2	GM ratio of Moon/Earth and Sun/Earth.
CFTER	7	1	Feet per earth radius.
CFTNM	8	1	Feet per nautical mile.
CKMER	9	1	Kilometers per earth radius.
CKMFT	10	1	Kilometers per foot.
	11		Not used.
CMTER	12	1	Meters per earth radius.

Name	Equivalence	Dimension	Description
CNMER	13	1	Nautical miles per earth radius
CBAYMN	14	12	Days per month, non-leap year.
CDEG	26	1	Degrees per radian
CJDSO	27	1	Julian Date of January 1, 1950
CPI	28	1	π radians
C2PI	29	1	2π radians
COMLST	30	1	Dimension of VSTR.
CFTEPS	31	1	Tolerance of convergence criterion in subroutine FIT.
CHMAX	32	1	Maximum integration step size, minutes.
CHMIN	33	1	Minimum integration step size, minutes.
CYMIN	34	1	Test parameter for subroutine TRAJ.
CER	35	1	Error bound for doubling and halving the integration step size.
CRASHE	36	1	Division criterion in TRAJ to avoid overflow in impact test.
CRASHM	37	1	Altitude at which test for earth impact is initiated, in earth radii.
	38-50		Not used.
KOUT	51	1	Output tape number.
KIN	52	1	Input tape number.
ITRJTP	53	1	Trajectory tape number.
MT	54	1	Observation tape number.
	58-60		Not used.

2.5.8 COMMON//BLK 2 (30)

Name	Equivalence	Dimension	Description
NPR	1	1	Size of solution vector.
NDPR	2	1	Number of CAT1 variables in solution vector.
NICPR	3	1	Number of α δ βARV in solution vector.
NAROW	4	1	Starting location in VSTR of row of A matrix and residual.
NATA	5	1	Starting location in VSTR of accymented normal matrix stored:



upper triangular by rows.

Name	Equivalence	Dimension	Description
NBONS	6	1	Starting location in VSTR of bounds vector.
NDPAR1	7	1	Starting location in VSTR of nominal bounds correction vector.
NDPAR2	8	1	Starting location in VSTR of correction vector based on bounds/2.
NDPAR3	9	1	Starting location in VSTR of correction vector based on bounds/4.
NDPAR4	10	1	Starting location in VSTR of correction vector based on bounds/8.
NIDLED	11	1	Starting location in VSTR of residual delete list.
NIDENT	12	1	Number of residual delete entries.

Name	Equivalence	Dimension	Description
NIDP	13	1	Starting location in VSTR of CATI variable indentification list.
NPAR	14	1	Starting location in VSTR of current estimate of solution variables.
NPBIS	15	1	Starting location in VSTR of current estimate of biases in solution vector.
NPRCD	16	1	Starting location in VSTR of CAT2 variable identification code words. Each word is of the form T*100+P where T is the bias type and P is the place in the solution vector. The bias type are: 1 . . . Range 2 . . . Azimuth 3 . . . Elevation 4 . . . Range rate 7 . . . Time 8 . . . Station latitude 9 . . . Station longitude 10 . . . Station height.
NR	17	1	Starting location in variable storage of covariance matrix from LEGS 2, stored lower triangular by rows.
NRTMP	18	1	Starting location in VSTR of temporary storage large enough to hold a lower triangular NPR x NPR matrix.
NSCALE	19	1	Starting location in VSTR of solution scale vector.
NSSTB	20	1	Starting location in VSTR of sensor mean and RMS table. 13 cells per sensor as follows:

Name	Equivalence	Dimension	Description
	i ... Station ID		
	i+1 ... ΣR residuals		
	i+2 ... ΣR^2 residuals		
	i+3 ... $NA_R*1000V+NR_R$		where NA = # of accepted points NR = # of rejected points
	i+4 ... ΣA residual		
	i+5 ... ΣA^2 residual		
	.		
	.		
	.		
	i+10 ... $\Sigma \dot{R}$ residuals		
	i+11 ... $\Sigma \dot{R}^2$ residuals		
	i+12 ... $NA_{\dot{R}}*10000+NR_{\dot{R}}$		
NSTAT	21	1	Starting location in VSTR of master sensor table. (See SENIN)
NUBS	22	1	Starting location in VSTR of observation storage. Observation fill VSTR from VSTR (NUBS) → VSTR (COMLST).
	23-30		Not used.

2.5.9 COMMON/ /BLK 3 (100)

Name	Equivalence	Dimension	Description
TEPOCH	1	1	Time of epoch, minutes from 0 hours.
TJDATE	2	1	Julian Date at 0 hours day of epoch.
TALFAG	3	1	Right ascension of Greenwich at 0 hours day of epoch. (radians)
DYEAR	4	1	Epoch year minus 1900.
DMNTH	5	1	Epoch month number.
DDAY	6	1	Epoch day number.

Name	Equivalence	Dimension	Description
DHOUR	7	1	Epoch hour.
DMIN	8	1	Epoch minute.
DSEC	9	1	Epoch seconds and fraction.
DTYPE	10	1	Type of input initial conditions.
	11-12		Not used
DBASE	13	1	Days from January 1, 1950 to epoch day.
PREFLG	14	10	Column 31-40 of the JDC.
DCFLG	24	10	Column 41-50 of the JDC.
PSTFLG	34	10	Column 51-60 of the JDC.
TNOMX	44	6	Nominal initial trajectory conditions in Cartesian coordinate, in kilometers and seconds.
TNOMP	50	6	Nominal initial trajectory conditions in polar coordinate, in kilometers, degrees and seconds.
CDAD2M	56	1	$\frac{C_d A}{2m}$ in feet squared/slug.
SGAMAM	57	1	$\frac{S\gamma A}{m}$ (Earth radii cubed/minute squared)
CKRMS	58	1	K for K*RMS residual deletion criterion.
CNSIG	59	1	N for N*SIGMA residual deletion criterion.
NITER	60	1	Maximum allowable iteration in curve fit.
TSTEP	61	1	Initial integration step size (minutes).

Name	Equivalence	Dimension	Description
DTMAX	62	1	Maximum allowable time interval for an observation, in days since epoch.
SKIP	63	1	Zero if evaluation of variational equation to be "predictor" only.
BFLAGS	64	2	Flags to indicate inclusion of sun and/or moon as perturbation force, non-zero to include.
DELTT	66	17	8 sets of trajectory print times Δt_1, T_1, Δt_2, T_2, $\cdots$ trajectory will be printed every Δt, minutes until T_1 minutes from epoch.
NDAYS	83	1	Number of day of ephemeris data for sun and moon (an integer from 0 to 10)
DVEHN	84	3	Columns 4-17 of the JDC. (BCD)
DHEAD	87	2	Columns 18-29 of the JDC. (BCD)
NMBER	89	1	Number of observation cards.

2.5.10 COMMON//BLK 4 (400) Working Storage

Name	Equivalence	Dimension	Description
TG	1	1	Integration time to go... minutes from 0 hours day of epoch.
TRAJX	2	57	Integration coordinates good at time TG:

$$x, y, z, \dot{x}, \dot{y}, \dot{z}, \ddot{x}, \ddot{y}, \ddot{z}, \frac{\partial x}{\partial p_1}, \frac{\partial y}{\partial p_1}, \frac{\partial z}{\partial p_1}, \frac{\partial \dot{x}}{\partial p_1}, \frac{\partial \dot{y}}{\partial p_1}, \frac{\partial \dot{z}}{\partial p_1}$$

$$\frac{\partial x}{\partial p_2}, \cdots$$

$$\vdots$$

$$\frac{\partial x}{\partial p_8}, \cdots \quad \cdots \quad \frac{\partial \dot{z}}{\partial p_8}$$

Name	Equivalence	Dimension	Description
			The p_1, p_2, ... p_8 are the CAT1 variables. Coordinates are stored in earth radii and minutes.
TLIST	59	192	Integration list (See TRAJ subroutine)
TALT	251	1	Vehicle altitude (feet)
TRHOA	252	1	Density of air at TALT (Slugs/cubic foot)
XN	253	6	Cartesian position of moon and sun relative to the earth for current integration day (Earth radii)
TICRT	265	6	Initial trajectory conditions in x, y, z, $\dot{x}$, $\dot{y}$, $\dot{z}$, in earth radii and minutes.
IPOL	271	6	Initial trajectory conditions in α, δ, β, A, R, V in earth radii, minutes, and radians.
PUBS	277	7	Observation vector =

PUBS (1) ... Station ID

PUBS (2) ... Time of observation (minutes from 0 hours of epoch day)

PUBS (3) ... Range (earth radii)

PUBS (4) ... Azimuth (radians)

PUBS (5) ... Elevation (radians)

PUBS (6) ... Range rate (earth radii/minute)

PUBS (7) ... Not used.

Name	Equivalence	Dimension	Description
PSIG	284	4	σ's for current PUBS list: σR, σA, σE, σR, in earth radii, radians, and minutes.
XBSQ	288	1	Multiplier for bounds to insure that solution from LEGS 2 is affected by $\frac{XBSQ*BOUNDS}{2}$

Name	Equivalence	Dimension	Description
COUNT	289	1	Line counter for residuals print.
IFTEX	290	1	Exit flag from FIT:

IFTEX = 1 ... Solution has converged

IFTEX = 2 ... maximum iteration exceeded and converging

IFTEX = 3 ... Failed K *BOUNDS/8

IFTEX = 4 ... Normal return

IFTEX = 5 ... Maximum iteration exceeded and diverging.

Name	Equivalence	Dimension	Description
TSUSP	291	1	Predicted RMS.
TSUSB	292	1	Best RMS.
TUBSEF	293	1	Non-zero when "end of file" encountered or observation tape.
KONTRL	297	1	Flag to indicate use of TRJGEN ... KONTRL = 1 ... Curve fit KONTRL = 2 ... Trajectory print and update
NDTCT	298	1	Current entry in DELTT array being processed.
NITCT	299	1	Current iteration number.
	300		Not used.
TCRASH	301	1	Non-zero if earth impact occurred.
TZ	302	1	Non-zero if solution affected by bounds.
PLSTSN	303	1	Station ID for previous observation.
TMBIS	304	1	Observation time bias (minutes).

Name	Equivalence	Dimension	Description
N1	305	1	Degree of highest zonal harmonic in earth's potential model.
N2	306	1	Degree of highest sectorial harmonic in earth's potential model.
N3	307	1	Degree of highest tesseral harmonic in earth's potential model.
FJ	308	12	FJ(I) is 0 if J_I not in zonal model, and FJ(I) = J_I is J_I in zonal model.
C	320	6, 6	Lower triangular portion contains: $C(N, M) = J_{NM} \cos (M\lambda_{NM})$ where J_{NM} are sectorial and tesseral harmonics and λ_{NM} are the corresponding phase angles.
S	356	6, 6	Lower triangular portion contain: $S(N, M) = J_{NM} \sin (M\lambda_{NM})$
PRMS	392	4	The RMS from the previous iteration of the range residuals, azimuth, elevation, and range rate.

Name	Equivalence	Dimension	Description
IFIT	396	1	An interger to indicate which corrections to apply to the solution vector:

IFIT = 1 . . . use solution for bounds

IFIT = 2 . . . use solution for bounds/2.

IFIT = 3 . . . use solution for bounds/4.

IFIT = 4 . . . use solution for bounds/8.

Name	Equivalence	Dimension	Description
CFLAG	396	1	A flag set non-zero when a non-impact iteration follows an impact iteration. When impact occurs, all convergence tests are suppressed until one iteration following a non-impact iteration.
			A flag set non-zero when impact occurs. This flag is set back to 0 following the next non-impact iteration. All convergence tests in FIT are suppressed until 2 non-impact iterations occur following an impact iteration.

3. DAP—DATA AVERAGING PROCESSOR

A complete mathematical and engineering description of DAP is given in "The Millstone Hill Radar Real Time Data Processor," Revision 1, by M. Deckett, 5452-6005-MU-001, TRW Systems, 29 September 1965. This section describes the input/output of DAP and pertinent subroutines.

Due to the time constraints, DAP was written so that all needed values were transmitted through COMMON or made available internally via the DATA statement. The use of subroutines was kept to an absolute minimum. Additionally, a table look-up was used instead of a standard cosine subroutine due to the required cosine accuracy. (See Appendix B reference.)

DAP, out of hardware necessity, simulates five real time program requirements:

1. Sense Switch 5 simulates the mode switch.
    a. SS 5 off (up) is equivalent to the Normal mode.
    b. SS 5 on (down) is equivalent to the Sparse mode.
2. Sense Switch 6 simulates the Data Processor Switch
    a. SS 6 off (up) is equivalent to Data Processor Switch on.
    b. SS 6 on (down) is equivalent to Data Processor Switch off.
3. Since the "Sample Ready Circuit" is not defined, there exists an area (prior to statement number 75) to insert logic to "Open Sample Ready Circuit".
4. The logic to "Correct Monopulse" is already built into DAP; however, it is bypassed since DELTA A and DELTA E are not available (Ref., p. 31).
5. The logic to rearrange data is to be placed at internal statement number four. (Ref., p. 19.)

Two additional DAP characteristics are worthy of mention. First, although DAP has not been subroutinized, there are definite logic blocks. The blocks are clearly labeled in the coding and coincide by name

and function with the "subroutines" as described in the reference. Second, to facilitate assimilation, variable names in DAP were chosen to match those appearing in the reference.

3.1 INPUTS

The required inputs to DAP are easily categorized as follows:

1. Values from real time radar, all integers.

	Description	Symbolic Location	Units
a.	Hit flag	ITTEMP (1)	0 or 1
b.	Range word	ITTEMP (2)	.5 μ sec
c.	Azimuth word	ITTEMP (3)	2^{-15} revs
d.	Elevation word	ITTEMP (4)	2^{-15} revs
e.	Doppler word	ITTEMP (5)	64 cps or 0
f.	Coarse time, the 23 most significant bits of a 29-bit time word	ITTEMP (6)	256×2^6 μ sec
g.	Fine time the 23 least significant bits of a 29-bit time word	ITTEMP (7)	256 μ sec
h.	Rearrange flag	ITTEMP (24)	=0; record data as presented ≠0; rearrange data before recording

2. Values from the preprocessor (PREMOD)

	Description	Symbolic Location	Format or Initial Value
a.	Target ID	DAPRE (1)	5 decimal digits (integer)
b.	GMT of tracking start day	DAPRE (2)	6 decimal digits (integer)
c.	72-character header label	DAPRE (3) thru DAPRE (14)	BCD

The following are flags initialized in the preprocessor:

	Name	Location	If zero	If non-zero	Initial value
a.	Mode	DAPRE (15)	normal	sparse	1
b.	Stop	DAPRE (16)	processor switch off	processor switch on	1
c.	Record	DAPRE (17)	do not record raw data	record raw data	From JDC card
d.	Break	DAPRE (18)	do not force end smoothing	force end of smoothing	
e.	Epsilon	DAPRE (19)	initialize base epoch word	do not initialize base epoch word	0
f.	Alpha	DAPRE (20)	initialize base azimuth word	do not initialize base azimuth word	0
g.	T	DAPRE (21)	new smoothing period	continuation of existing smoothing period	0
h.	Mode Change Enable	DAPRE (22)	remain in normal mode	switch to sparse mode	0
i.	Output	DAPRE (23)	record output	do not record output	0
j.	DTZ	DAPRE (24)	adjust time	do not adjust	
k.	DC*	DAPRE (25)	adjust time	do not adjust	
l.	First	DAPRE (26)	initialize epoch update word	do not initialize epoch update word	0
m.	Header	DAPRE (40)	do not write header	write header	1

*DC is set non-zero when MHESPOD is entered

The following are critical constants and biases:

	Description	Symbolic Location	Value if Not Input	Units
a.	Range editor critical deviation	DAPRE (28)	16500.	meters
b.	Range rate editor critical deviation	DAPRE (29)	9.	m/sec
c.	Smoothing time	DAPRE (30)	5.25	seconds
d.	Time bias	DAPRE (31)	0	seconds
e.	Range bias	DAPRE (32)	0	meters
f.	Range rate bias	DAPRE (33)	0	m/sec
g.	Elevation bias	DAPRE (34)	0	degrees
h.	Azimuth bias	DAPRE (35)	0	degrees

3. Values from MCOM (COMMON)

Description	Symbolic Location	Units
Range sigma	SIGMA (1)	earth-radii
Azimuth sigma	SIGMA (2)	radians
Elevation sigma	SIGMA (3)	radians
MHESPOD Epoch Time	TEPOCH	minutes

4. Values from DAPNTP

	Description	Symbolic Location	Units
a.	Ephemeris interpolation flag	DAPSTR (1)	0 = interpolation allowed 1 = interpolation not allowed
b.	Time	DAPSTR (2)	Minute from midnite of start day
	Radius	DAPSTR (3)	Earth radii
	Azimuth	DAPSTR (4)	Radians
	Elevation	DAPSTR (5)	Radians
	$\partial R/\partial T$	DAPSTR (6)	Earth radii/minute
	$\partial A/\partial T$	DAPSTR (7)	Radians/minute
	$\partial E/\partial T$	DAPSTR (8)	Radians/minute

3.2 OUTPUTS

1. Save tape for later processing.
   a. Header record consisting of:
      1. Word 1 —Integer count of the words in the record, excluding the first word
      2. Word 2 —Program identifying word "DAP"
      3. Word 3 —Target identifier
      4. Word 4 —GMT of day of tracking commencement
      5. Words 5—16
         —72-character label chosen by the user
   b. Raw data record in standard format
      1. Word 1 —Integer count of words in record excluding the first word
      2. Word 2 —Target identifier
      3. Word 3 —GMT of day of tracking commencement
      4. Words 4—10
         —Radar data as shown under INPUTS 1, a through g.
   c. Raw data in rearranged format
      To be accomplished at a later date
   d. Averaged data
      1. Word 1 —Integer count of the words in the record, excluding the first word
      2. Word 2 —Target identifier
      3. Word 3 —GMT of day of tracking commencement
      4. Word 4 —Time of averaged data in minutes 0 hr day shown by word 1
      5. Word 5 —Range in earth radii
      6. Word 6 —Range rate in earth radii/min
      7. Word 7 —Elevation in radians
      8. Word 8 —Azimuth in radians
      9. Word 9 —Normalized variance of sample
   e. Termination record
      1. Word 1—1
      2. Word 2—0

2. Standard output tape

   a. Average data—see words 4 through 9 Section 1.d.

   b. Administrative messages

      1. "NOEPHM" indicates the request ephemeris time was not on the ephemeris tape.

      2. "DAPBOF FULL .... MESPOD WILL NOT RECEIVE ANY MORE DATA" indicates the alloted storage in MESPOD for average data points is filled and no further points will be stored for MESPOD.

      3. Averaged Data to MESPOD

         DAP will place up to 60 sets of averaged data into a designated storage area in COMMON. The data is in the order and form of Section 1.d, words 4 through 9.

3.3 SUBROUTINES

DAP uses three subroutines, as follows:

1. DAPNTP—For a detailed description see Section 5.3. This routine is used to interpolate the core ephemeris. Communication is through DAPSTR; see INPUTS, Section 4.

   USAGE: CALL DAPNTP

2. SSWITCH—The IBM FORTRAN IV routine to check the status of a given sense switch.

   USAGE: CALL SSWTCH (X, Y)

   X = sense switch to be interrogated

   Y = cell set to; 1 if X down
   2 if X up

3. OVERFL—The IBM FORTRAN IV routine to determine if floating point overflow exists.

   USAGE: CALL OVERFL (X)

   X = Cell set to; 1 if overflow
   2 if no overflow

   In either case, the machine is left in a no overflow condition.

4. LAP—LOOK ANGLE PROCESSOR

The LAP module provides steering signals to the radar servo, and obtains these by interpolating the core ephemeris, a radar observables table (for Millstone Hill sensor) given as 60 equally spaced arguments. When LAP is initiated, it first reads the computer real time clock. This argument time is corrected by subtracting a constant time bias which is provided as an input constant, but which in later versions of the real time system may be calculated from the real data.

Because the first derivatives are available for four of the output values, ($R\ A\ E\ \dot{R}$), a modified Everett's formula is used. The resulting interpolation is effectively a three-point (quadratic) form for $\dot{R}\ \dot{A}\ \dot{E}$ and a four-point (cubic) form for $R\ \dot{R}\ A\ E$. The resulting accuracy of the interpolation is related to the spacing of the arguments of the core ephemeris, the "curvature" of the given sighting ephemeris, and the characteristics of the interpolating formulas used.

4.1 LAP CONTROL

LAP is used only when a sequence of conditions and events permits. The Test Director must request that the radar servo be switched to LAP mode, and that the 9300 be enabled by command to accept the interrupt. This is, of course, predicated upon the presence of the activated real time system in the 9300. Further, LAP does not operate when MHESPOD, or any other program, is modifying the core ephemeris. The LAP control logic is diagramed in Figure 4-1.

4.2 LAP SUBROUTINE DESCRIPTION

Subroutine LAP assumes a core ephemeris, a 60 equally spaced time history of Millstone Hill radar observables, has been generated and interpolates the observables using a modified Everett's formula. The observables are corrected for biases; in addition, the elevation is corrected for servo-lag and propagation error; the azimuth is corrected for servo-lag.

The output is returned as an 8-element vector as shown in Item 4. Figure 4-2 is a simplified flow chart of the subroutine.

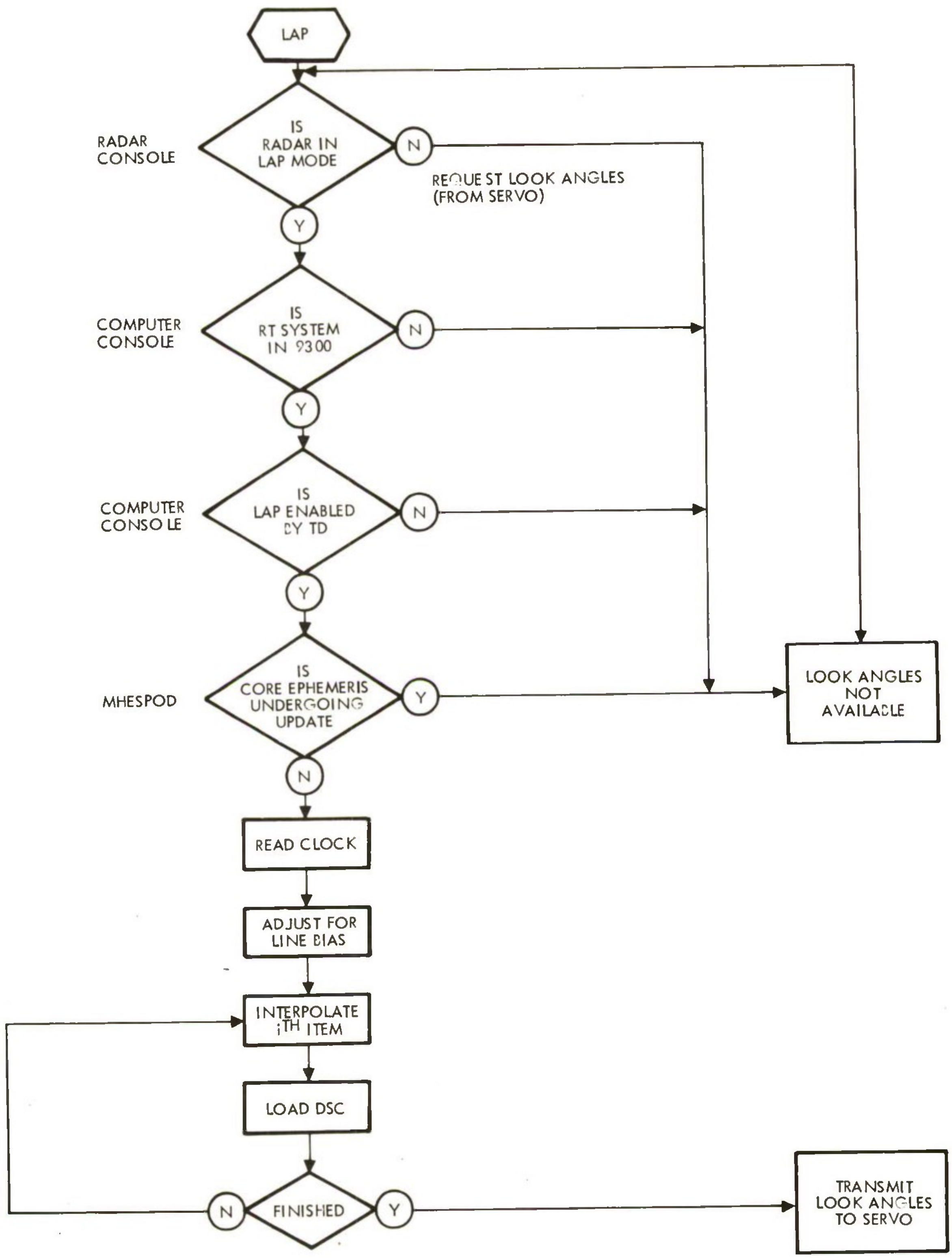


Figure 4-1. LAP Control Logic

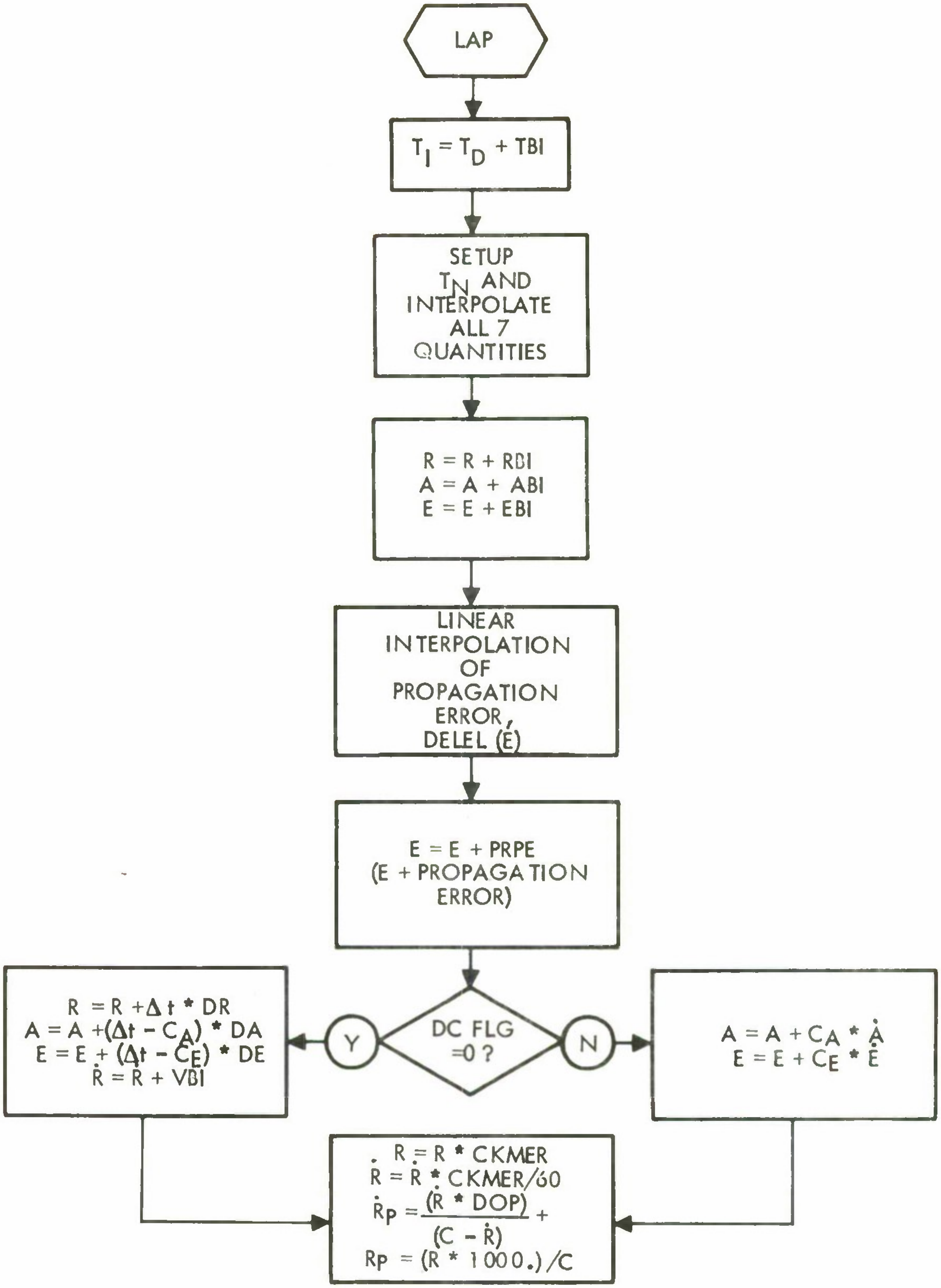


Figure 4-2. LAP Subroutine Flow Diagram

The following is a description of the inputs and output of SUBROUTINE LAP. There are no variables in the calling sequence. Everyting is done through the following named common blocks.

1. /CE/CE (484)

CE (1) = Δt	Δt = time interval of ephemeris
CE (2) = $t_\alpha + \Delta t$	t_α = initial value of time of ephemeris
CE (3) = $t_\beta - 1\Delta t$	t_β = final value of time of ephemeris
CE (4) = DCFLG	

The arrangement of the rest of CE is a function of CE (4) or the DCFLG

1.0	=	CE (4)	=	0.0
t	=	CE (5), CE (13), . . .	=	t
$\ddot{R}$ (ER/MIN^2)	=	CE (6), CE (14), . . .	=	$\dot{R}$ (ER/MIN)
R (ER)	=	CE (7), CE (15), . . .	=	R (ER)
A (DEG)	=	CE (8), CE (16), . . .	=	A (DEG)
E (DEG)	=	CE (9), CE (17), . . .	=	E (DEG)
$\dot{R}$ (ER/MIN)	=	CE (10), CE (18), . . .	=	∂R (ER/MIN)
$\dot{A}$ (DEG/MIN)	=	CE (11), CE (19), . . .	=	∂A (DEG/MIN)
$\dot{E}$ (DEG/MIN)	=	CE (12), CE (20), . . .	=	∂E (DEG/MIN)

Only the dimensions of R and $\dot{R}$ are critical as they are not returned in their table dimension, in the output vector.

2. /DAPRE/DAPRE (40)

DAPRE (31)	=	time bias	TBI
DAPRE (32)	=	range bias	RBI
DAPRE (33)	=	velocity bias	VBI
DAPRE (34)	=	elevation bias	EBI
DAPRE (35)	=	azimuth bias	ABI
DAPRE (36)	=	azimuth servo-lag	CSUBA
DAPRE (37)	=	elevation servo-lag	CSUBE

3. /BLK1/EL (9) = elevation

/BLK2/DELEF (9) = elevation propagation error

4. /LAPSTR/NCEFG, TD, RDOT, R, A, E, RDOTP, RP

NCEFG	= 0,	Interpolation was possible
NCEFG	= 1,	No interpolation, time was outside the range of the ephemeris
TD	=	Time at which $\dot{R}$, R, A, E, etc. are to be evaluated. Must be stored by calling program.
RDOT	=	$\dot{R}$ in km/sec
R	=	Range in km
A	=	Azimuth in ephemeris units
E	=	Elevation in ephemeris units
RDOTP	=	$\dot{R}$ in Doppler
RP	=	Range in milliseconds

5. PROGRAM FUNCTIONAL DESCRIPTION

5.1 SUBROUTINE LOGIC

The diagrams on the following pages illustrate the subroutine structure of the MHESPOD and NRTPOD programs. A functional diagram of PREMOD is given in Section 1.1. Figure 5-1 illustrates the main flow of MHESPOD. The subroutines shown in this figure are principally drivers for other routines. The subroutines which are called by the main drivers are listed in Figure 5-2, the MHESPOD subroutine hierarchy. A lower heirarchy is indicated by positioning down and to the right. For example, subroutine DAUX calls subroutine RPRESS (radiation pressure), which in turn calls EVERT (for interpolation). These two diagrams are similar to Figure 1-2, which is an analyst's description of the MHESPOD program.

Figure 5-3 is a diagram of the NRTPOD overlay structure in terms of the principal options of the program. Since the program is restricted in size, not all routines can fit into core at any one time. The NRTPOD overlay structure is detailed by subroutines in Figure 5-4. From this figure, it can be seen which subroutines are in core as a function of the particular option of the program (as defined in Figure 5-3). It should be noted that the routines which are common to all program functions, such as PIMOD (modulates an angle between 0 and 2π), occupy the top of the overlay structure.

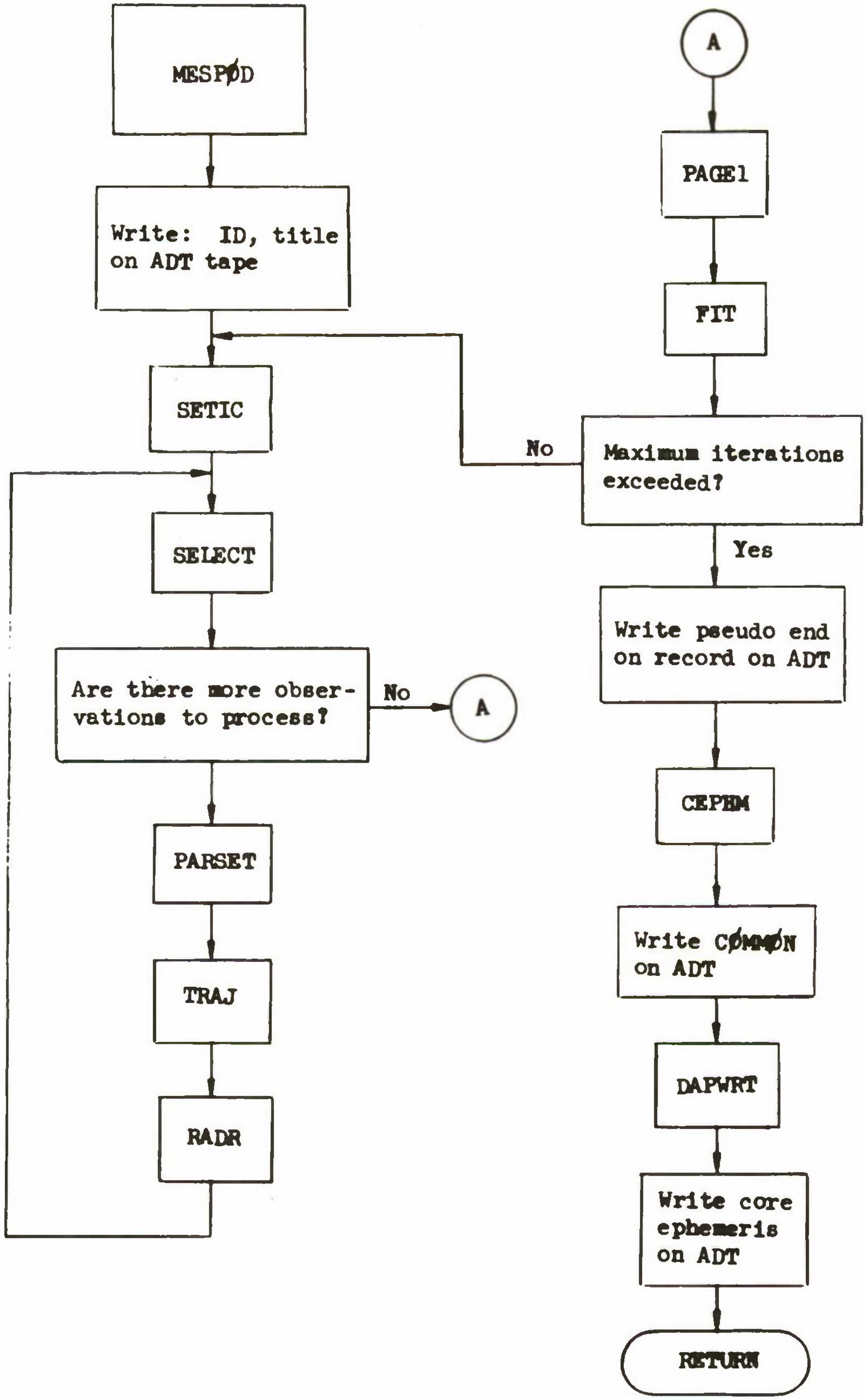


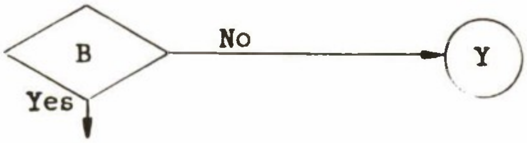
Figure 5-1. General Subroutine Logic of MHESPOD Program

```
MESPØD        SETIC ─────────────────────────── (Y)
                        VPERT
                        DAUX
                                      BØDY
                                                    EVERT
                                      RPRESS
                                                    EVERT
                                      PØTENT
                                                    GPERT
                                      DRAG
                                                    JACHIA
                                                                  ATM59
                                      VAREQ
                                      Exit to
              SETIC
              SELECT
                        UBSGET
                        Exit to
              SELECT
               <A>      Yes ─────────────────── (Z)         A.  Has the last observa-
              No                                                tion been processed?
              PARSET
              TRAJ
                        DAUX (see above)
              RADR
                        PRELIM
                        DRDP
                        LEGS1
                        PAGE1
                        Exit to
              RADR      Loop to
              SELECT

              ┌──────────────────────────────── (Z)
              PAGE1
              FIT
                        LEGS2
                        APPLY
                        Exit to
```

Figure 5-2. MHESPOD Subroutine Hierarchy

```
        FIT
```



B. Maximum iterations?

```
        CEPHM
                SETIC
                        VPERT
                        DAUX (see above)
                TRAJ
                        DAUX (see above)
                CEGEN
                CEAZ
        DAPWRT
MESPØD
```

Figure 5-2. MHESPOD Subroutine Hierarchy (Continued)

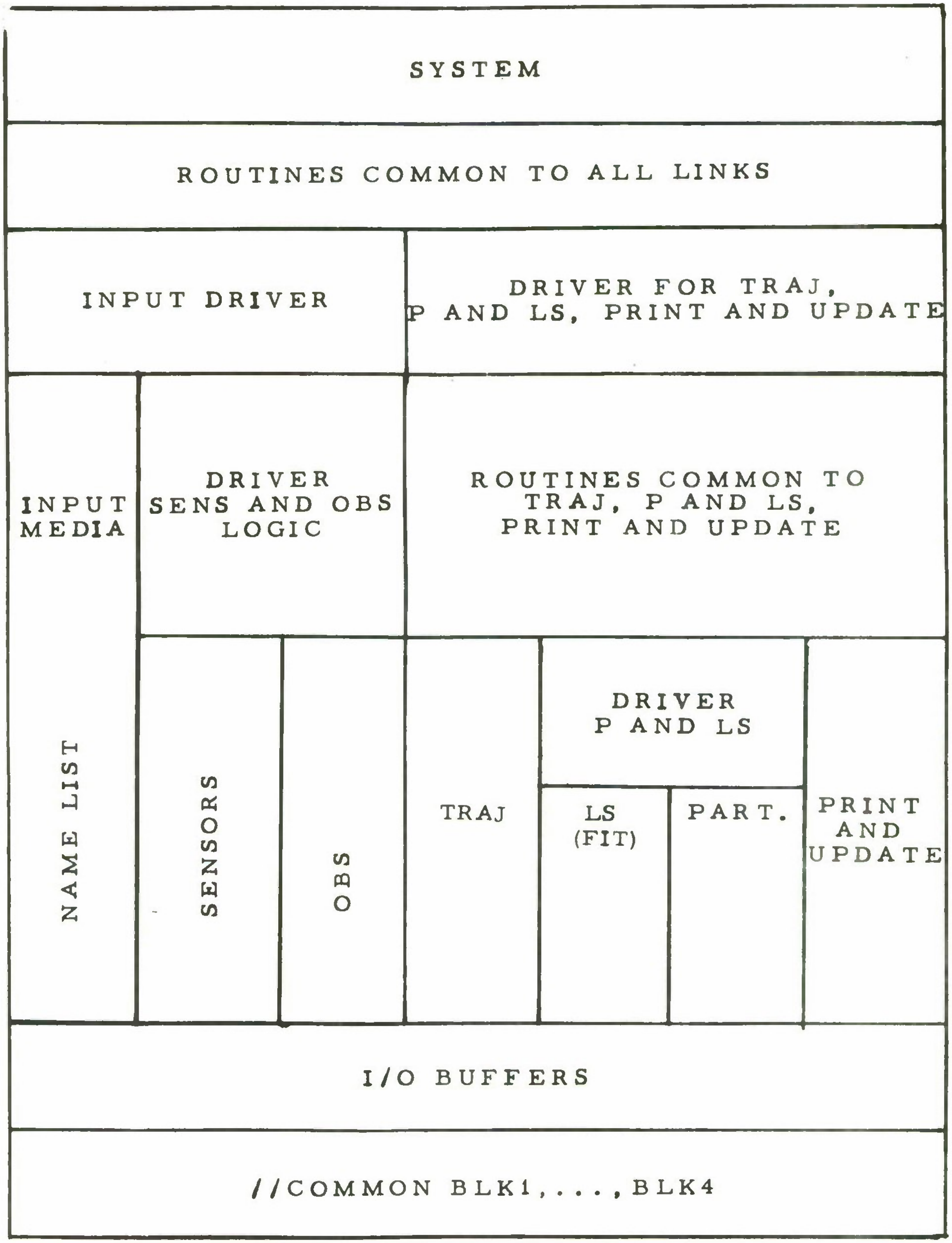


Figure 5-3. NRTPOD Overlay

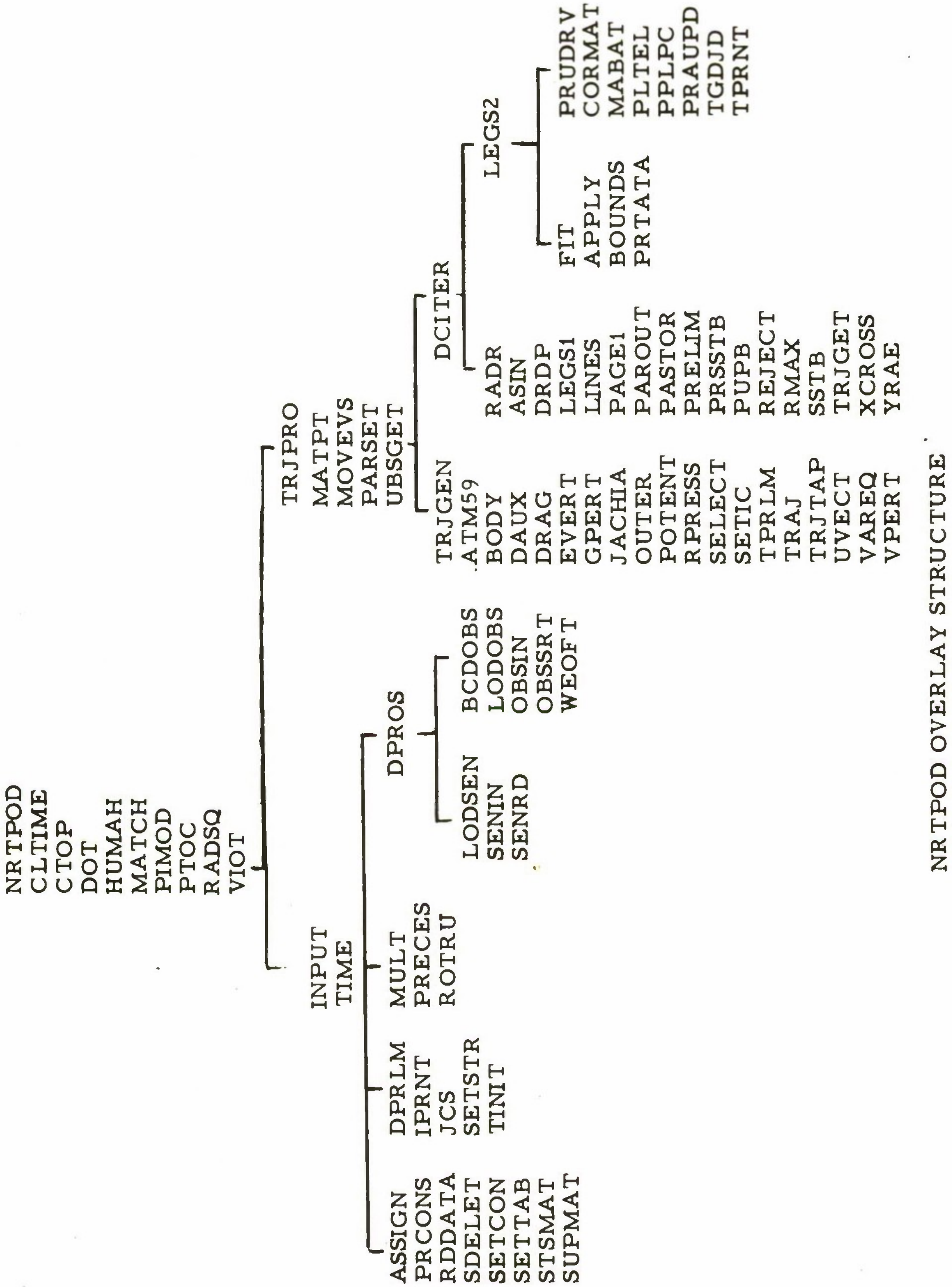


Figure 5-4. NRTPOD Overlay Structure

5.2 GLOSSARY OF SUBROUTINES

This section lists the subroutines which are used by the programs. i.e., PREMOD, MHESPOD, and NRTPOD. If a particular subroutine or operation is unknown in name to the reader, the functional description can be helpful in identifying the appropriate subroutine(s). The program code identifies the program(s) in which a particular subroutine is used; the code letters are:

P: PREMOD
M: MHESPOD
N: NRTPOD

Some of the subroutines which are in the glossary have not been included in the subroutine descriptions (Section 5.3) since they are essentially as described in ESPOD documentation (ESPOD Mathematical and Subroutine Description, June 1964). These particular subroutines are identified by an asterisk. If the same subroutine is significantly different in the two or more referenced programs, separate descriptions are given.

Subroutine	Program	Functional Description
APPLY	M	Applies corrections to solution vector, prints iteration summary on-line, and writes information on ADT tape
APPLY	N	Applies corrections to solution vector and prints iteration summary
ASIN*	P, M, N	Arcsine routine
ASSIGN	N	Establishes storage assignments for arrays in variable storage
ATM59	P, M, N	Computes density of a static atmosphere (ARDC 1959 Model)
BCDOBS	N	Reads an observation card
BODY	P, M, N	Computes acceleration due to sun and moon
BOUNDS	N*	Scales bounds with given scale factor
CDCD	P	Modulates the input time
CEAZ	M	Smooths the azimuth arguments in the core ephemeris

Subroutine	Program	Functional Description
CEGEN	P, M	Generates one point of the core ephemeris
CEPHM	M	Generates a 60-point core ephemeris
CLTIME	N	Computes Gregorian time
COMSET	P	Prepares MESCOM for BCT Tape
CORMAT	N	Computes correlation matrix
CTOM	P	Converts a Cartesian state vector to mean elements
CTOP*	P, N	Converts a Cartesian state vector to polar spherical coordinates (ADBARV)
DAPOB	P	Reads DAP observations from the ADT Tape and writes them on the BCT Tape
DAPRT	P	Prints the observations from the DAP Tape
DAPWRT	M	Processes DAP observations and writes them on the ADT Tape
DAUX	P, M, N	Driver for evaluating acceleration in integration
DCITER	N	Driver for the computation of the normal matrix and one iteration of the DC
DLSTV	P	Computes the differentials for the MTOC and CTOM conversions
DOBPRT	P	Prints the DAP observations from the ADT Tape
DOT	P, M, N	Computes scalar product
DPRLM	P, N	Data initializing (partial)
DPROS	N	Driver for loading observation and sensor cards
DRAG	P, M, N	Computes drag perturbations
DRDP	M, N	Computes partial of observations w.r.t. category 1 variables
EVERT	P, M, N	Interpolates position of sun and moon
FIT	M, N	Logic control for DC options
GENCE	P	Generates the core ephemeris

Subroutine	Program	Functional Description
GPERT	P, M, N	Computes acceleration due to Earth's potential
HUMAH	P, N	Converts a vector, A^TA matrix, or $(A^TA)^{-1}$ from machine units to human units or vice-versa
INPUT	N	Main driver for input processor
IPRNT	P, N	Prints header page
JACHIA	P, M, N	Computes air density using Lockheed-Jacchia atmospheric model
JCBINV	P	Computes inverse of variational equations matrix using Jacobi inverse technique
JCS	P, N	Sets up vector of zonal coefficients $J_2 \cdots J_{12}$ and two matrices of C's and S's for GPERT
JTOC	P	Converts Julian date to calendar date
LEGS1	M, N	Forms A^TA and A^TB given A and B
LEGS2	M, N	Least squares package solves $AX = B$
LINES	N	Ejects page and prints heading at top of page
LODOBS	P, N	Main control for observation card processor
LODSEN	P, N	Main control for sensor card processor
MABAT	P, N	Multiplies ABA^T where B is a lower triangular matrix
MATCH	P, N	Compares two floating point variables
MATPT	P, N	Prints lower triangular matrix
MOVEVS	N	Moves observation set from variable to working storage
MTOC	P	Converts mean elements to Cartesian coordinates
MULT	P, N	Multiplies a 3 x 3 matrix by a succession of 1 x 3 vectors
NRTPOD	N	Main control for NRTPOD
OBSIN	N	Moves observations from buffer to permanent storage

Subroutine	Program	Functional Description
OBSRD	P	Reads observation card
OBSSRT	N	Sorts observations to time sequence
OUTER	P, M, N	Computes product of column and row vector
PAGE1	M	Accumulates residuals and outputs them on the ADT Tape
PAGE1	N	Acummulates residuals and prints
PAROUT	N	Computes residuals for residuals print
PARSET	M, N	Initializes station data for partial derivative package
PASTOR	N	Monitors residual rejection
PIMOD	P, M, N	Obtains positive argument of an angle in radians between 0 and 2π
PLTEL	N	Converts polar elements to indeterminancy free and orbital elements
POTENT	P, M, N	Driver for geopotential model
PPLPC	N	Computes partial of ADBARV w.r.t. Cartesian
PRAUPD	N	Updates a covariance matrix to a specified time
PRCONS	N	Prints program constants
PRECES	P, N	Processes lunar-solar ephemerides from mean of 1950.0 to true of epoch coordinates
PRELIM	P, M, N	Makes preliminary calculations in partials package
PREMOD	P	Main control subroutine of PREMOD
PRTADT	P	Formats and prints the ADT Tape
PRSSTB*	N	Computes and prints mean, RMS, and number for residuals by sensor and type
PRTATA	N	Stores and prints the A^TA matrix
PRUDRV	N	Main driver for trajectory print and update package

Subroutine	Program	Functional Description
PTOC*	P, N	Converts polar coordinates to Cartesian coordinates
PUPB*	N	Computes partial of observation w.r.t. category 2 variables; i.e., t_b, ϕ_b, λ_b, h_b
RADR	M, N	Computes residuals; driver for partials package
RADSQ	P, M, N	Computes magnitude and (magnitude)^2 of a 3-D vector
RDCOM	P	Reads/MESCOM/record from ADT Tape
RDDATA	P	Reads NAMELIST input cards, ephemeris cards, and mean elements cards
RDDATA	N	Reads NAMELIST input cards and ephemeris cards
REJECT	N	Monitors the acceptance or rejection of an observation
RMAX	N	Compares residual quantities with table of maximum values
ROTRU*	P, N	Rotates a set of vectors from mean of 1950.0 to true of date coordinates
RPRESS	P, M, N	Computes perturbative acceleration due to radiation pressure
SDELET	N	Moves deletion list from buffer to permanent storage
SELECT	M, N	Selects next observation time
SENIN	P, N	Moves sensor data from buffer to permanent storage
SENRD	P, N	Reads three types of sensor cards
SETCON	P, N	Sets constants for program
SETIC	P, M, N	Initializes integration list
SETSTR	P, N	Converts drag and radiation pressure parameters from external to internal units
SETTAB	N	Sets tables concerning solution vector in variable storage

Subroutine	Program	Functional Description
SSTB*	N	Accumulates sum, sum of squares, and number of residuals by sensor and data type
STSMAT*	N	Converts upper triangular S matrix from human units to machine units
SUPMAT*	N	Moves input update matrix from buffer to permanent storage
TGDJD*	N	Converts Julian to calendar date from integration time and prints
TINIT*	P, N	Sets up initial time, computes α_{go}
TIME*	P, N	Converts Y, M, D, H, M, S to Julian date: days plus fraction
TPRLM*	N	Sets up data for integration
TPRNT*	N	Prints trajectory print
TRAJ	P, M, N	Integrates the equations of motion and variational equations of motion to a specified time
TRISE	P	Searches for rise
TRJGEN	N	Main driver for trajectory package
TRJGET	N	Reads trajectory record from trajectory tape from DC package
TRJPRO	N	Main driver for DC, trajectory, and update interfaces
TRJTAP	N	Writes trajectory tape
TSET	P	Establishes final time of core ephemeris
UBSGET	M, N	Gets next observation time from variable storage
UPDATE	P	Driver for covariance matrix update logic
UVECT	P, N	Unitizes a 3-dimensional vector
VAREQ	P, M, N	Computes second derivatives of variational equation
VPERT	P, M, N	Initializes variational equations

Subroutine	Program	Functional Description
WEOFT	N	Writes an ending sentinel block on observation tape
WRTCOM	P, N	Writes COMMON block on observation tape
WRTOBS	N	Generates observation tape
XCROSS*	N	Performs the cross product of two 3-dimensional vectors
YRAE*	N	Computes Y vector when range, azimuth, and elevation are given

SUBROUTINE IDENTIFICATION

A. Title

APPLY

B. Segment

MHESPØD

C. Called by subroutine

FIT

FUNCTION

Function is to apply DC solution vector, print iteration summary on-line, and write information on ADT Tape.

USAGE

A. Calling sequence

Call APPLY

B. Input

1. CØMMØN

NDPAR1	Starting location of solution vector in variable storage
NDPR	Total number of Category 1 variables to solve for
NITCT	Iteration counter
NPAR	Starting location of parameter list in variable storage
PØBCNT	Total number of observables
KADT	Logical unit for ADT Tape
NATA	Location of A^TA in VSTR
NSCALE	Starting location of the list of conversion factors
NR	Starting location of where the $(A^TA)^{-1}$ is stored

TICRT	Nominal Cartesian coordinates
TEMP	Temporary storage
TNØMX	Initial Cartesian coordinates
TSUS	Current total SØS
TSUSP	Predicted SØS for next iteration
VSTR	Variable storage
CKMER	Km/ earth radii
NDAPØB	Number of DAP observations

2. Calling sequence

—

C. Output

1. CØMMØN

—

2. Calling sequence

—

D. Error/action messages

—

SUBROUTINES USED

A. Library

SQRTF

B. Program

—

EQUATIONS

$$RMS_{\Delta t} = \sqrt{\frac{\sum(\Delta t_i)^2}{N}}$$

APPLY

where N is the number of measurements in the Δt fit

$$RMS_{\Delta t} \text{ predicted} = \sqrt{\frac{\sum\left(\Delta t_i\right)^2 - \frac{\left[\sum\left(\Delta t_i\right)^2\right]^2}{\sum\left(t_i - to\right)^2}}{N}}$$

SUBROUTINE IDENTIFICATION

A. Title

APPLY

B. Segment

NRTPOD partials least square

C. Called by subroutine

FIT

FUNCTION

At the end of each curve-fit iteration APPLY adds the correction vector to the current values of the differential correction parameters. The iterative summary is then printed.

USAGE

A. Calling sequence

Call APPLY

B. Input

1. COMMON

CDAD2M	$C_DA/2m$
NBDNS	Starting location of bounds vector in variable storage
NDPAR1	Starting location of solution vector in variable storage
NDPR	Total number of category 1 variables to solve for
NICPR	Total number of spherical coordinates to solve for
NIDP	Pointer in IVSTR for CAT1 identifiers
NITCT	Iteration counter
NPAR	VSTR pointer for parameter list
NPBIS	VSTR pointer for current CAT2 estimates

NPR	Total number of parameters to solve for
NPRCD	IVSTR pointer for CAT2 identifiers
NSCALE	VSTR pointer for conversion factors used to convert solution vector
NSSTB	VSTR pointer where station mean and RMS information is stored
NSTAT	VSTR pointer for master sensor table
NR	VSTR pointer for $(A^TA)^{-1}$
NRTMP	Pointer for temporary storage
TICRT	Nominal Cartesian coordinates
TIPOL	Nominal spherical coordinates
TNOMP	Initial spherical coordinates
TNOMX	Initial Cartesian coordinates
TSUS	Current SOS
TSUSB	Best SOS
TSUSP	Predicted SOS for next iteration
TZ	Indicates if solution was affected by bounds
VSTR	Variable storage
CDEG	degrees/radian
CKMER	kilometer/earth radii
IOUT	Peripheral output tape number

2. Calling sequence

IFIT = 1 apply solution using nominal bounds
= 2 apply solution using bounds/2
= 3 apply solution using bounds/4
= 4 apply solution using bounds/8

C. Output

1. COMMON

—

2. Calling sequence

3. Iteration summary

APPLY

SUBROUTINES USED

A. Library

.FCNV.

.FFIL.

.FPRN.

.FVIO.

.FWRD.

SQRT

B. Program

HUMAH

MATPT

PRTATA

PTOC

SUBROUTINE IDENTIFICATION

A. Title

ASSIGN

B. Segment

NRTPOD - INPUT PROCESSOR

C. Called by subroutine

INPUT

FUNCTION

The function is to establish storage assignments for the arrays to be located in variable storage (VSTR). This routine also establishes NPR, NDPR, and NICPR.

USAGE

A. Calling sequence

Call ASSIGN

B. Input

1. COMMON

/INPP/ DATA (1000)

2. Calling sequence

—

C. Output

1. COMMON

NPR	Total number of all parameters to solve for
NDPR	Number of differential and initial parameters to solve for (Category 1)
NICPR	Number of initial condition parameters to solve for
NAROW	Starting location where one row of augmented matrix (A, B) is stored

NATA	Starting location of where the triangular A^TA is stored
NBDNS	Starting location for the bounds used by LEGS
NDPAR1 NDPAR2 NDPAR3 NDPAR4	Starting locations where the 4 sets of solution vectors will be stored
NIDLED	Starting location of where the observation deletion table begins
NIDENT	Number of entries in the NIDLED list
NIDP	Identifier for table indicating CAT 1 type variables to be solved for
NPAR	Identifies the starting location for the parameter list
NPBIS	Identifies table for current estimates of CAT 2 variables
NPRCD	Identifies table for definition of CAT 2 variables to be solved for
NR	Starting location of where the inverse A^TA is stored (in triangular form)
NRTMP	Identifies the starting location of temporary storage for special handling of the R matrix
NSCALE	Location of the list of conversion factors which convert all solution vectors and associated matrices from machine to output units and vice versa
NSTAT	Starting location of the master sensor table
VSTR	Floating point variable storage

2. Calling sequence

—

D. Error/action messages

—

SUBROUTINES USED

A. Library

—

B. Program

—

EQUATIONS

NICPR	=	Number of orbital elements to solve for
NDPR	=	CAT1 variables
NPR	=	CAT1 + CAT2
NIDP	=	1
NPRCD	=	NDPR + NIDP
NPBIS	=	NPR - NDPR + NPRCD
NAROW	=	NPR - NDPR + NPBIS
NBDNS	=	NPR + 1 + NAROW
NPAR	=	NPR + NBDNS
NDPAR1	=	2*NPR + NPAR
NDPAR2	=	NPR + NDPAR1
NDPAR3	=	NPR + NDPAR2
NDPAR4	=	NPR + NDPAR3
NSCALE	=	NPR + NDPAR4
NIDLED	=	NPR + NSCALE
NATA	=	NIDENT + 2 + NIDLED
NR	=	[(NPR + 1) * (NPR + 2)]/2 + NATA
NRTMP	=	[(NPR + 2) * (NPR + 3)]/2 -1 + NR
NSTAT	=	[(NPR + 1) * NPR]/2 +1 + NRTMP

FLOW CHART

See EQUATIONS for order of computation.

SUBROUTINE IDENTIFICATION

A. Title

ATM59

B. Segment

MHESPOD
PREMOD
NRTPOD

C. Called by subroutine

JACHIA

FUNCTION

The function is to interpolate from the atmosphere tables the density of the atmosphere at given altitudes, using the standard ARDC 1959 model.

USAGE

A. Calling sequence

Call ATM59 (A, B)

B. Input

1. COMMON

—

2. Calling sequence

Address of altitude (meters)

C. Output

1. COMMON

—

2. Calling sequence

Address of density (slugs/ft^3)

SUBROUTINES USED

A. Library

EXP

B. Program

—

EQUATIONS

$$H = \frac{g_o}{G}\left[\frac{rZ}{r + Z}\right] \qquad (1)$$

$$\rho = \rho_b \left[\frac{(T_M)_b}{(T_M)_b + L_M (H - H_b)}\right]^{1+(GM_o/R^* L_M)} \quad \text{for } L_M \neq 0 \qquad (2)$$

$$\rho = \rho_b \exp\left[\frac{-GM_o(H - H_b)}{R^*(T_M)_b}\right] \quad \text{for } L_M = 0 \qquad (3)$$

where b refers to the value of the quantity at the base of the constant gradient layer.

Note:

Equation (1)

H = geopotential altitude

g_o = acceleration of gravity

G = conversion constant

$= \frac{9.80665\ M^2}{\sec^2\ M^1}$ where M^1 is meters of geopotential

r = effective Earth radius at latitude $45^\circ 32' 33''$

Z = geometric altitude

Equations (2) and (3)

ρ = density obtained from calculation

ρ_b = density at the base of a constant gradient layer where these base values were obtained.‡

$(T_M)_b$ = molecular-scale temperature at the base of a constant gradient layer. ‡

‡ R.A. Minzner, K.S. Champion, and H.L Pond, The ARDC Model Atmosphere, 1959 Air Force Surveys in Geophysics No. 115 (AFCRC-TR-59-267) Air Force Cambridge Res. Center, August 1959.

ATM59

L_M = molecular scale temperature gradient

$$= \frac{T_M - (T_M)_b}{H - H_b}$$

M_o = sea level value of molecular weight

R^* = universal gas constant

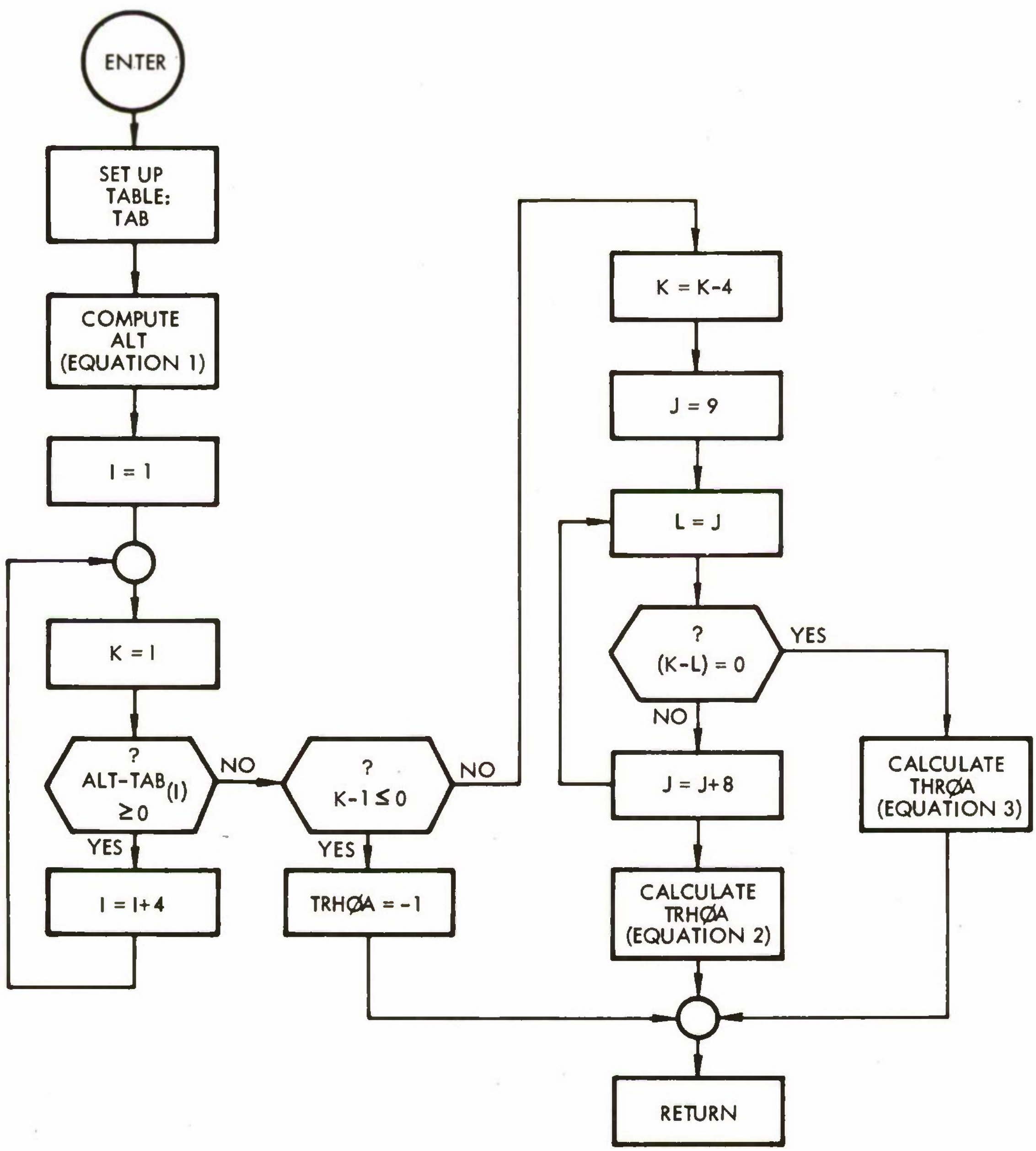


Figure 5-5. ATM59 Flow Diagram

SUBROUTINE IDENTIFICATION

A. Title

BCDOBS

B. Segment

NRTPOD - INPUT PROCESSOR

C. Called by subroutine

LODOBS

FUNCTION

To read one observation card and process the estimated standard deviations carried on the observation cards. Additional functions include processing of types 1 and 2 observation cards (Lincoln Laboratory Format) and detecting the last observation card to be processed.

USAGE

A. Calling sequence

Call BCDOBS (A, SEOF)

B. Input

1. COMMON

KOUT	Symbolic output tape number
KIN	Symbolic input tape number

2. Calling sequence

—

C. Output

1. COMMON

A(1)	Satellite ID (A)
A(2)	Year
A(3)	Month
A(4)	Day

A(5)	Hour
A(6)	Minutes
A(7)	Seconds
A(8)	Observation type
A(9)	Range - R (km)
A(10)	Azimuth (deg) positive east of north
A(11)	Elevation (deg)
A(12)	Range derivative $\dot{R}$ (km/sec)
A(13)	Standard deviation of Range (km)
A(14)	Standard deviation of azimuth (deg)
A(15)	Standard deviation of elevation (deg)
A(16)	Standard deviation of velocity (km/sec)

2. Calling sequence

SEOF — End of observation card read - signals end of observation data = ±1

SEOF = -1 more obs to be processed
SEOF = +1 no more obs to be processed

D. Error/action messages

1. Off line comment when program encounters types 1 and 2 observation cards:

"PROGRAM IGNORES TYPES 1 AND 2 OBSERVATION CARDS"

2. Action

Program proceeds to process next observation card.

(A) Indicates alphanumeric

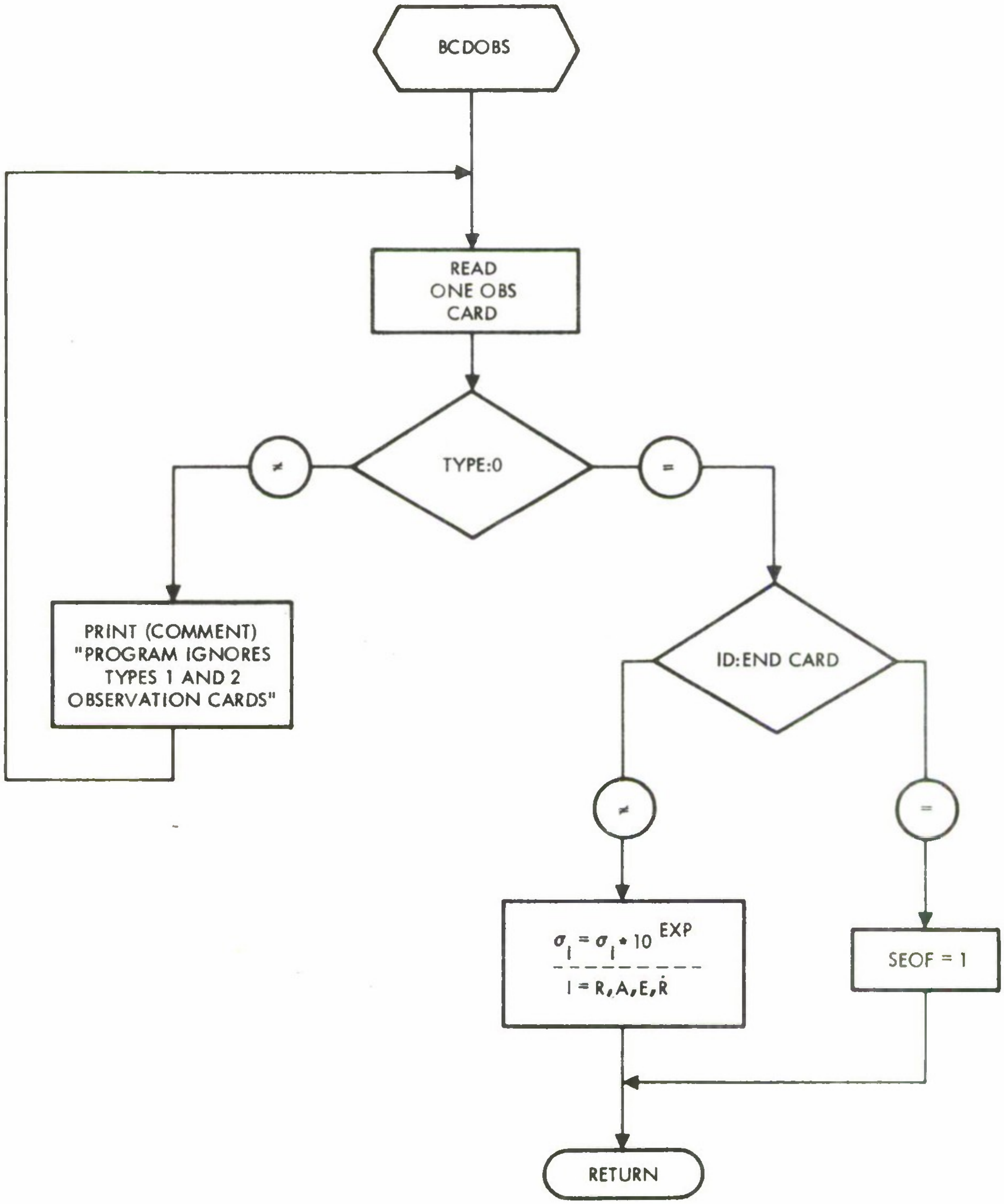


Figure 5-6. BCDOBS Flow Diagram

SUBROUTINE IDENTIFICATION

A. Title

BODY

B. Segment

MHESPOD
PREMOD
NRTPOD

C. Called by subroutine

DAUX

FUNCTION

The function is to compute the perturbative acceleration of a spacecraft due to other bodies in the solar system and to account for these effects in the variational equations.

USAGE

A. Calling sequence

Call BODY

B. Input

1. COMMON

TLIST	Current integration list
BDASE	Days from 1950.0 to midnight day of epoch
CMU	GM of Earth (e.r.^{3}/min^2)
CGMR	Ratio of moon, sun GM to that of the Earth
FLVE	Flag to skip computation of variational equations
BFLAGS	Flags to indicate whether the accelerations of the moon and sun are to be considered (used in NRTPOD version only)
NDAYS	NAMELIST input variable denoting the number of days of lunar-solar ephemeris impart. (used in NRTPOD version only)

2. Calling sequence

C. Output

1. COMMON

TBPERT	The total acceleration of the vehicle due to all the desired bodies
PMAT	Matrix of the position dependent effects in the variational equations (the body effects are added to this matrix)
XN	Cartesian position of Moon and Sun

2. Calling sequence

—

SUBROUTINES USED

A. Library

—

B. Program

EVERT

RADSQ

OUTER

EQUATIONS

The position of the Moon and Sun with respect to the Earth, x_i, y_i, z_i, is obtained from the ephemeris cards.

$$R_i = \left(x_i^2 + y_i^2 + z_i^2 \right)^{1/2}$$

$$x_{vi} = x_v - x_i$$

$$y_{vi} = y_v - y_i$$

$$z_{vi} = z_v - z_i$$

where x_v, y_v, z_v is the position of the vehicle with respect to the earth.

$$R_{vi} = \left(x_{vi}^2 + y_{vi}^2 + z_{vi}^2 \right)^{1/2}$$

$$\ddot{x}_{bodies} = - \sum_{i=1}^{u} \mu_i \left[\frac{(x_v - x_i)}{R_{vi}^3} + \frac{x_i}{R_i^3} \right]$$

$$\ddot{y}_{bodies} = - \sum_{i=1}^{u} \mu_i \left[\frac{(y_v - y_i)}{R_{vi}^3} + \frac{y_i}{R_i^3} \right]$$

$$\ddot{z}_{bodies} = - \sum_{i=1}^{u} \mu_i \left[\frac{(z_v - z_i)}{R_{vi}^3} + \frac{z_i}{R_i^3} \right]$$

$$\text{PMAT} = \text{PMAT} + \begin{bmatrix} \sum_{i=1}^{u} \mu_i \left(\frac{3x_{vi}^2}{R_{vi}^5} - \frac{1}{R_{vi}^3} \right) & \sum_{i=1}^{u} \mu_i \left(\frac{3x_{vi}\, y_{vi}}{R_{vi}^5} \right) & \sum_{i=1}^{u} \mu_i \left(\frac{3x_{vi}\, z_{vi}}{R_{vi}^5} \right) \\ \sum_{i=1}^{u} \mu_i \left(\frac{3x_{vi}\, y_{vi}}{R_{vi}^5} \right) & \sum_{i=1}^{u} \mu_i \left(\frac{3y_{vi}^2}{R_{vi}^5} - \frac{1}{R_{vi}^3} \right) & \sum_{i=1}^{u} \mu_i \left(\frac{3y_{vi}\, z_{vi}}{R_{vi}^5} \right) \\ \sum_{i=1}^{u} \mu_i \left(\frac{3x_{vi}\, z_{vi}}{R_{vi}^5} \right) & \sum_{i=1}^{u} \mu_i \left(\frac{3y_{vi}\, z_{vi}}{R_{vi}^5} \right) & \sum_{i=1}^{u} \mu_i \left(\frac{3z_{vi}^2}{R_{vi}^5} - \frac{1}{R_{vi}^3} \right) \end{bmatrix}$$

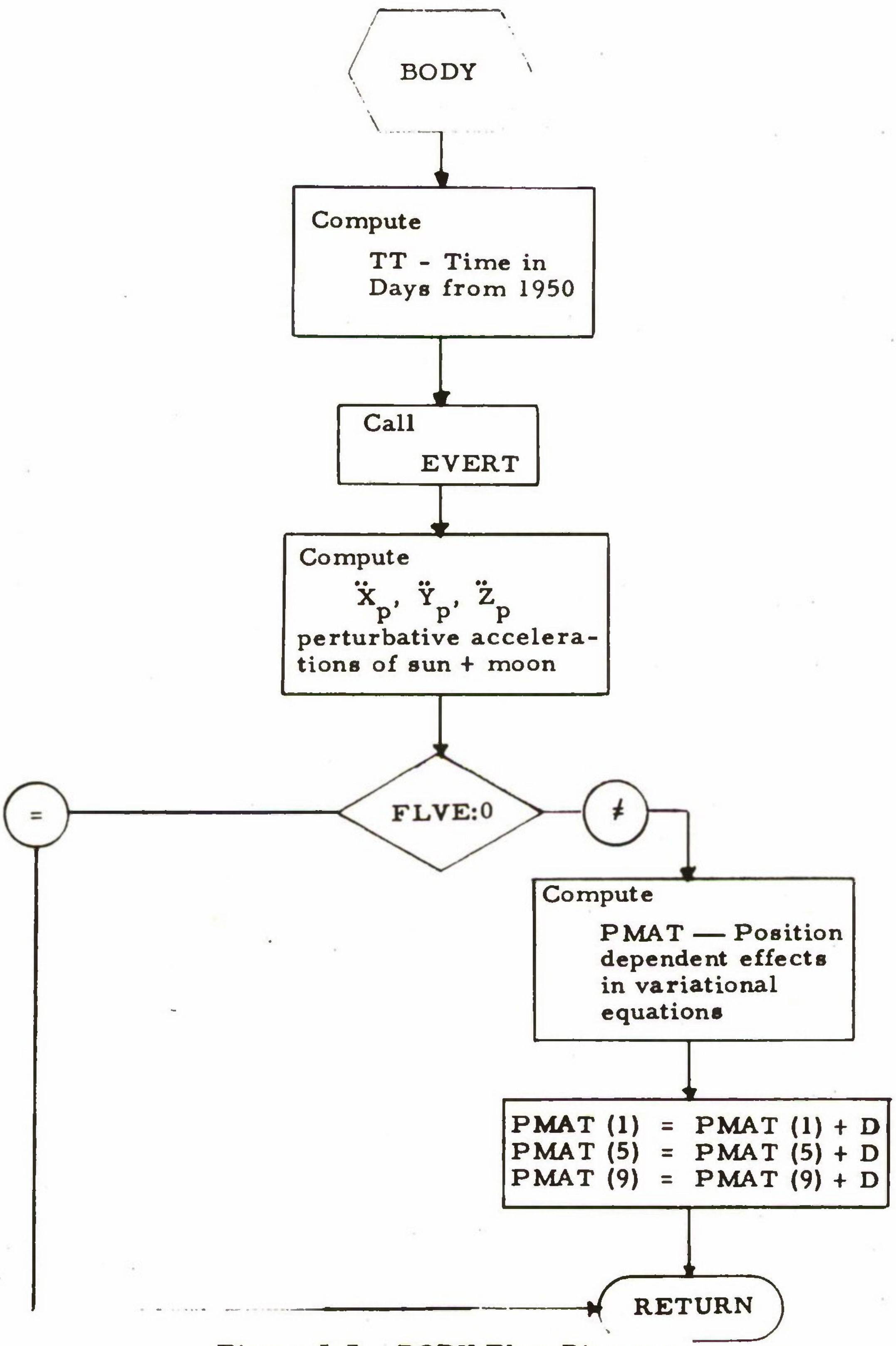


Figure 5-7. BODY Flow Diagram

SUBROUTINE IDENTIFICATION

A. Title

CDCD

B. Program

PREMOD

C. Called by subroutine

JTOC

FUNCTION

To modulate the Gregorian calendar date. Upon exit:

Seconds < 60
Minutes < 60
Hours < 24
Days $\leq$ days in current month
Month ≤ 12

No provision is made for fractional time except for seconds.

USAGE

A. Calling sequence

Call CDCD (YEAR, TMNTH, DAY, HOUR, TMINS, SEC)

B. Input

1. COMMON

CDAYMN Days in each month (non-leap year)

2. Calling sequence

YEAR	Year Number		
TMNTH	Month Number	$0 < \text{TMNTH} \leq \infty$	Positive integers
DAY	Day Number	$0 < \text{DAY} \leq \infty$	Positive integers
HOUR	Hours	$0 \leq \text{HOUR} \leq \infty$	Positive integers
TMINS	Minutes	$0 \leq \text{TMINS} \leq \infty$	Positive integers
SEC	Seconds	$0 \leq \text{SEC} \leq \infty$	Positive integers

C. Output

1. COMMON

None

2. Calling sequence

TMNTH Month number $0 < \text{TMNTH} \leq 12$

DAY	Day number	$0 < DAY \leq$ Days in TMNTH
HOUR	Hours	$0 \leq HOUR < 24$
TMINS	Minutes	$0 \leq TMINS < 60$
SEC	Seconds	$0 \leq SEC < 60$

D. Error/Action Messages

None

SUBROUTINES USED

A. Library

None

B. Program

None

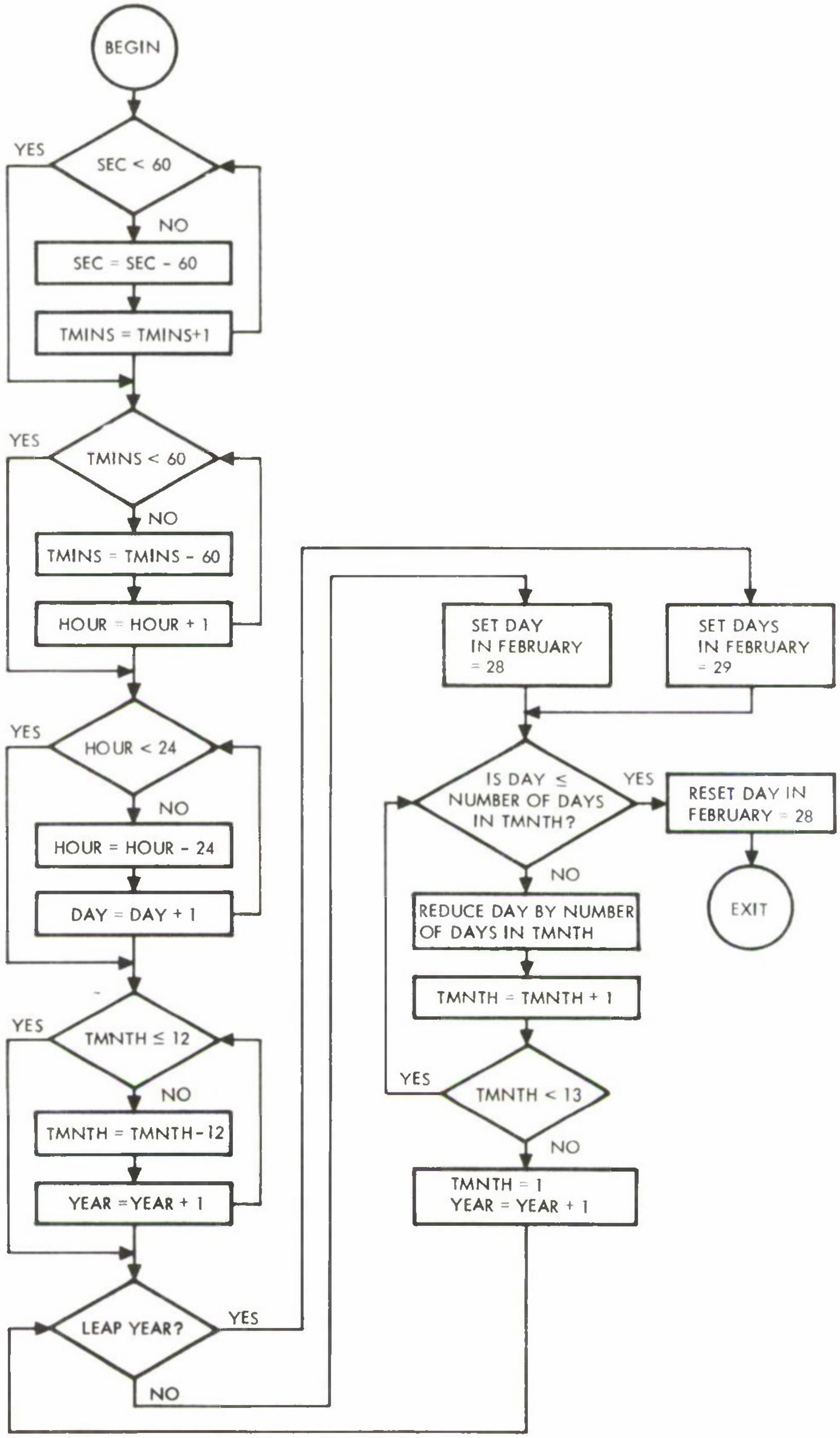


Figure 5-8. CDCD Flow Diagram

SUBROUTINE IDENTIFICATION

A. Title

CEAZ

B. Segment

MHESPØD

C. Called by subroutine

CEPHM

FUNCTION

To eliminate any jumps in the stored azimuths of the core ephemeris. The conventional notation for azimuth restricts it to a principal interval from 0° to 359.999°, resulting in a jump of $\pm 360^{\circ}$ at the crossover. This routine eliminates this jump by adding 360° to the appropriate stored azimuths.

USAGE

A. Calling sequence

Call CEAZ

B. Input

1. Labeled CØMMØN

/CE/		Core ephemeris cells
/MESCØM/		MHESPØD CØMMØN variables
	CPI	
	C2PI	2

2. Calling sequence

—

C. Output

1. CØMMØN

/CE/	Azimuth core ephemeris cells

2. Calling sequence

—

D. Error/action messages

—

SUBROUTINES USED

A. Library

ABS

B. Program

—

SUBROUTINE IDENTIFICATION

A. Title

CEGEN

B. Segment

MHESPØD

PREMØD

C. Called by subroutine

CEPHM

FUNCTION

To generate one point of the core ephemeris.

$t, \dot{R}, R, A, E, \partial R/\partial t, \partial A/\partial t, \partial E/\partial t$, if running PREMØD;

or: $t, \ddot{R}, R, A, E, \dot{R}, \dot{A}, \dot{E}$, if running MHESPØD.

USAGE

A. Calling sequence

Call CEGEN (A)

B. Input

1. Labeled CØMMØN

/CE/	Core ephemeris cells
/MESCØM/	MHESPØD CØMMØN variables
NDPR	Number of parameters to solve for
PUDTI	Vector ($\dot{u}_1$, $\dot{u}_2$, $\dot{u}_3$)
PSTAT	
CWE	Earth's rotational rate
PWI	Vector (w_1, w_2, w_3)
TRAJX	
PCSALF	
PSNALF	

PUBS(2)	
PCMR	R = computed slant range
PVI	Vector (v_1, v_2, v_3)
PUI	Vector (u_1, u_2, u_3)
PWDTI	Vector $(\dot{w}_1, \dot{w}_2, \dot{w}_3)$
PV	$v_1^2 + v_2^2$
TEMP	Temporary storage

2. Calling sequence

—

C. Output

1. CØMMØN

—

2. Calling sequence

A - eight variable array containing

$t, R, R, A, E, \frac{\partial R}{\partial t}, \frac{\partial A}{\partial t}, \frac{\partial E}{\partial t}$ when executing PREMØD

or

$t, \ddot{R}, R, A, E, \dot{R}, \dot{A}, \dot{E}$ when running MHESPØD

D. Error/action messages

—

SUBROUTINES USED

A. Library
CØS
SIN

B. Program
PRELIM
ATNQ
PIMØD
ASIN

EQUATIONS

$$a = (ag_o + \lambda) + \omega_e (t - t_o) \tag{1}$$

$$\begin{bmatrix} W_1 \\ W_2 \\ W_3 \end{bmatrix} = \begin{bmatrix} \cos a & \sin a & 0 \\ -\sin a & \cos a & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \tag{2a}$$

$$\begin{bmatrix} \dot{W}_1 \\ \dot{W}_2 \\ \dot{W}_3 \end{bmatrix} = \begin{bmatrix} \cos a & \sin a & 0 \\ -\sin a & \cos a & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \dot{X} + \omega_e Y \\ \dot{Y} - \omega_e X \\ \dot{Z} \end{bmatrix} \tag{2b}$$

$$A_S = (\cos^2 \phi^* + b_e^2 \sin^2 \phi^*)^{-1/2} \tag{3}$$

$$B_S = (\sin^2 \phi^* + \frac{1}{b_e^2} \cos^2 \phi^*)^{-1/2} \tag{4}$$

where

ω_e = earth rotational rate

b_e = polar axis of reference ellipsoid

$$W_1^5 = (A_S + h) \cos {}^{*} \tag{5}$$

$$W_3^5 = (b_e B_S + h) \sin {}^{*} \tag{6}$$

$$q_1 = W_1 - W_1^5 \tag{6a}$$

$$q_2 = W_2 \tag{6b}$$

$$q_3 = W_3 - W_3^5 \tag{6c}$$

$$R = \sqrt{q_1^2 + q_2^2 + q_3^2} \tag{7}$$

$$\left.\begin{aligned} u_1 &= q_1/R & (8a)\\ u_2 &= q_2/R & (8b)\\ u_3 &= q_3/R & (8c)\end{aligned}\right\} \text{Topocentric direction cosines in equatorial system}$$

$$\vec{u} = u_1 \vec{i} + u_2\vec{j} + u_3\vec{k} \tag{8d}$$

$$K = u_1\dot{W}_1 + u_2\dot{W}_2 + u_3\dot{W}_3$$

$$\dot{u}_1 = (\dot{W}_1 - Ku_1)/R \tag{9a}$$

$$\dot{u}_2 = (\dot{W}_2 - Ku_2)/R \tag{9b}$$

$$\dot{u}_3 = (\dot{W}_3 - Ku_3)/R \tag{9c}$$

$$\dot{\vec{u}} = (\dot{u}_1\vec{i} + \dot{u}_2\vec{j} + \dot{u}_3\vec{K} \tag{9d}$$

$$\left.\begin{aligned} v_1 &= u_2 & (10a)\\ v_2 &= -u_1 \sin \phi^* + u_3 \cos \phi^* & (10b)\\ v_3 &= u_1 \cos \phi^* + u_3 \sin \phi^* & (10c)\end{aligned}\right\} \text{Topocentric direction cosines in horizon system}$$

$$\vec{v} = v_1\vec{i} + v_2\vec{j} + v_3\vec{K} \tag{10d}$$

$$\dot{v}_1 = \dot{u}_2 \tag{11a}$$

$$\dot{v}_2 = -\dot{u}_1 \sin\phi^* + \dot{u}_3 \cos\phi^* \tag{11b}$$

$$v_3 = u_1 \cos\phi^* + u_3 \sin\phi^* \tag{11c}$$

$$V = \sqrt{v_1^2 + v_2^2} \tag{12}$$

$$\ddot{W}_1 = -\omega_3^2\, W_2 - 2\omega_e\, (\dot{y} \cos a + \dot{x} \sin a)$$
$$+ (\ddot{y} \cos a - \ddot{x} \sin a) \tag{13a}$$

$$\ddot{W}_2 = -\omega_e^2\, W_2 - 2\omega_e\, (\dot{x} \cos a + \dot{y} \sin a)$$
$$+ (\ddot{y} \cos a - \dot{x} \sin a) \tag{13b}$$

$$W_3 = \ddot{Z} \tag{13c}$$

$$\vec{\ddot{W}} = \ddot{W}_1\vec{i} + \ddot{W}_2\vec{j} + \ddot{W}_3\vec{K} \tag{13d}$$

$$\frac{\partial W_1}{\partial t_o} = + (\dot{x} \cos a + \dot{y} \sin a) \tag{14a}$$

$$\frac{\partial W_2}{\partial t_o} = - (\dot{x} \sin a - \dot{y} \cos a) \tag{14b}$$

$$\frac{\partial W_3}{\partial t_o} = \dot{Z} \tag{14c}$$

The foregoing equations define the core ephemeris. All quantities have been defined in equations (1) through (14).

$$R = \sqrt{q_1^2 + q_2^2 + q_3^2} \tag{15}$$

$$A = \tan^{-1} (v_1/v_2) \tag{16}$$

$$E = \sin^{-1} (v_3) = \cos^{-1} (V) \tag{17}$$

$$\dot{R} = \vec{u} \cdot \dot{\vec{W}} \tag{18}$$

$$\dot{A} = \frac{1}{V^2} (v_2 \dot{v}_1 - v_1 \dot{v}_2) \tag{19}$$

$$\dot{E} = \dot{v}_3/V \tag{20}$$

$$\ddot{R} = \vec{u} \cdot \ddot{\vec{w}} + \dot{\vec{u}} \cdot \dot{\vec{w}} \tag{21}$$

$$\frac{\partial R}{\partial t_o} = u_1 \frac{\partial W_1}{\partial t_o} + u_2 \frac{\partial W_2}{\partial t_o} + u_3 \frac{\partial W_3}{\partial t_o} \tag{22}$$

$$\frac{\partial A}{\partial t_o} = \frac{1}{RV} \left[\frac{\partial W_2}{\partial t_o} \cos A - \left(\frac{\partial W_1}{\partial t_o} \sin \phi^* + \frac{\partial W_3}{\partial t_o} \cos \phi^* \right) \sin A \right] \tag{23}$$

$$\frac{\partial E}{\partial t_o} = \frac{1}{RV} \left[\frac{\partial W_1}{\partial t_o} \cos A - \frac{\partial W_3}{\partial t_o} \sin \phi^* - \frac{\partial R}{\partial t_o} \sin E \right]$$

SUBRØUTINE IDENTIFICATIØN

A. Title

CEPHM

B. Segment

MHESPØD

C. Called by subroutine

MHESPØD

FUNCTIØN

Generates a 60-point core ephemeris as a function of some start time, t_α, and some last observation time, t_α'.

USAGE

A. Calling sequence

CALL CEPHM

B. Input

1. labeled CØMMØN

/MESCØM/ MHESPØD CØMMØN variables.

CEP1	= 60, integer which controls size of core ephemeris intervals
TNØDE	Time of core ephemeris termination
PUBS(2)	Time (min) of core ephemeris point
TEMP	Temporary storage

2. Calling sequence

—

C. Output

1. CØMMØN

/CE/	Core ephemeris cells. CE(1-4) - core ephemeris control cells, CE(5-484) - 60 ephemeris points.

2. Calling sequence

—

D. Error/action messages

—

SUBRØUTINES USED

A. Library

AINT

B. Program

SETIC

TRAJ

CEGEN

CEAZ

EQUATIØNS

t_f	=	Final time, input by analyst
t_o	=	Time of epoch
t_s	=	Time of set (-1.5^o horizon)
t_Ω	=	Earliest of t_f, $t_o + 60$, t_s
t_α'	=	Time of epoch, or, if post-epoch data present, time of last observation
P_1	=	60, integer which controls the size of the core ephemeris interval
P_2	=	60, the number of points in the core ephemeris ($P_2 > 4$)
P_3	=	Integer part of $\frac{P_1(t_\alpha' - t_\Omega)}{P_2 - 3}$

 CEPHM

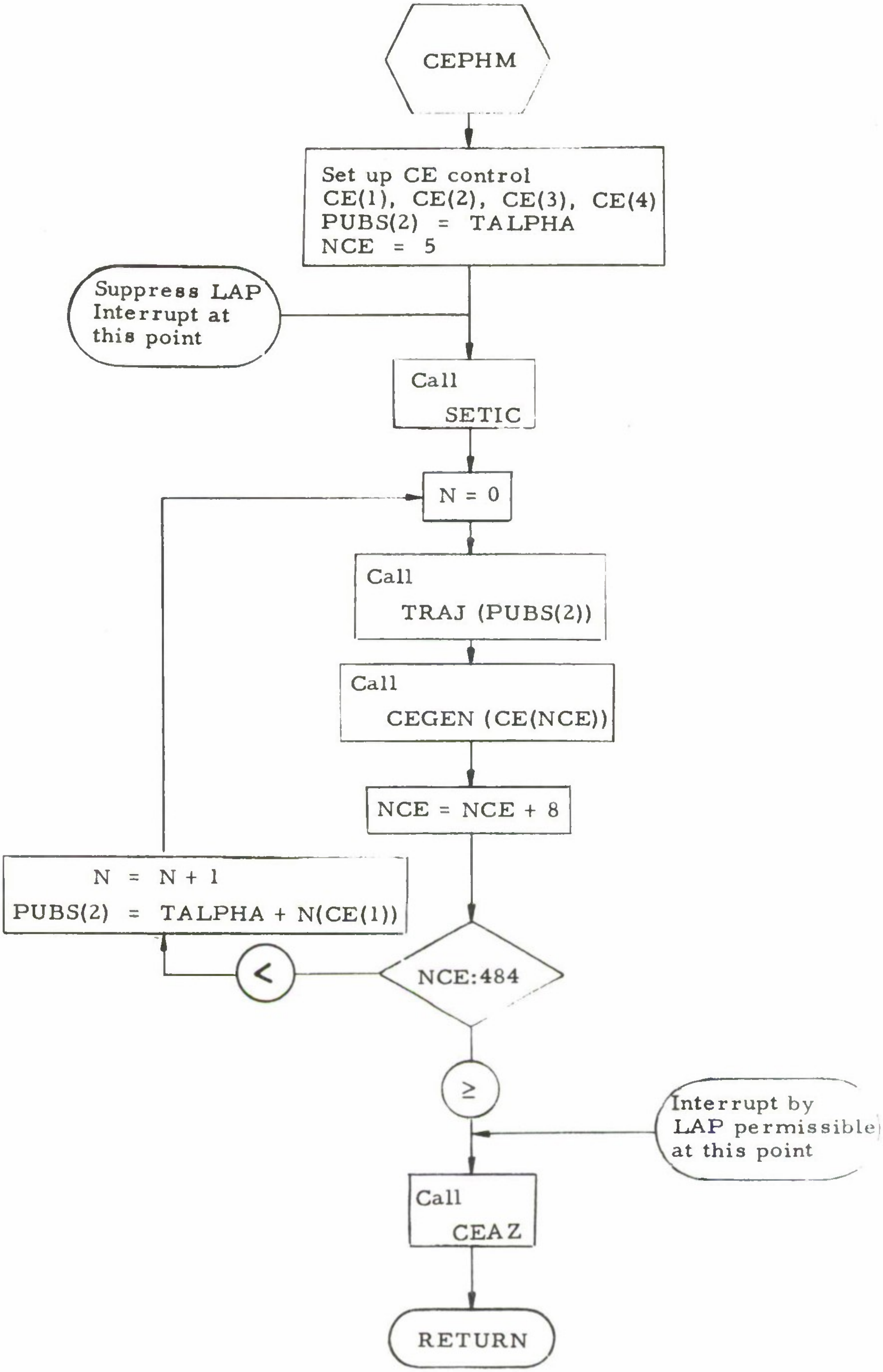


Figure 5-9. CEPHM Flow Diagram

SUBROUTINE IDENTIFICATION

A. Title

CLTIME

B. Segment

NRTPOD - INPUT PROCESSOR

C. Called by subroutine

TTAPE [PRINT AND UPDATE LINK]

TGDJD [PRINT AND UPDATE LINK]

LODOBS [INPUT PROCESSOR LINK]

FUNCTION

To compute the calendar date referenced to epoch, given time in minutes from epoch.

USAGE

A. Calling sequence

Call CLTIME (TMIN, TIME)

B. Input

1. COMMON

CDAYMN	12-cell array containing the number of days in each month. (28 set for FEB)
DYEAR	Epoch year
DMNTH	Epoch month
DDAY	Epoch day
DHOUR	Epoch hour
DMIN	Epoch minutes
DSEC	Epoch seconds

2. Calling sequence

TMIN	Time in minutes referenced to epoch

C. Output

1. COMMON

—

2. Calling sequence

TIME (1)	YEAR
TIME (2)	MONTH
TIME (3)	DAY
TIME (4)	HOUR
TIME (5)	MINUTES
TIME (6)	SECONDS

D. Error/action messages

—

SUBROUTINES USED

A. Library

AINT	Floating point integer
AMOD	Mod function routine

B. Program

—

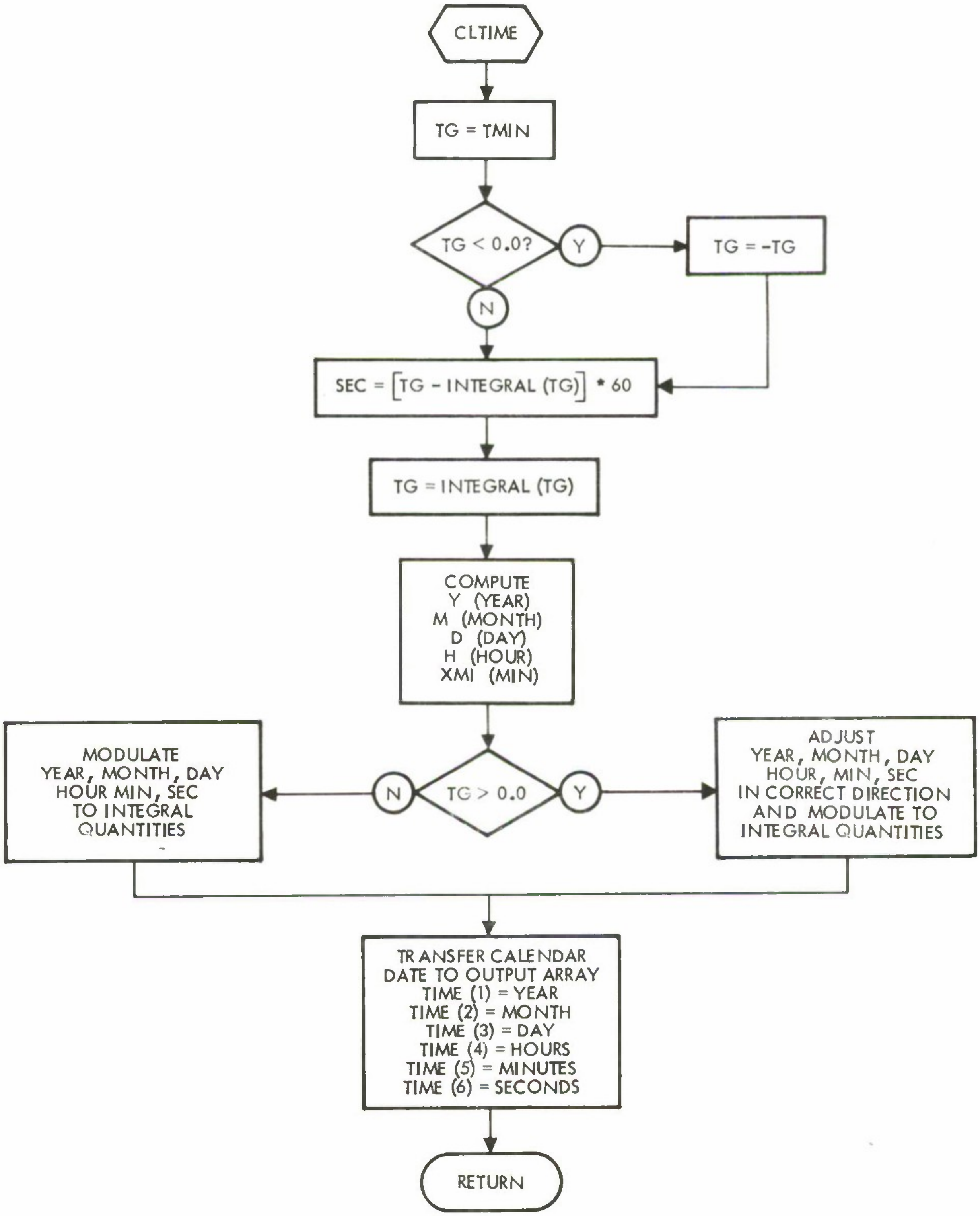


Figure 5-10. CLTIME Flow Diagram

SUBROUTINE IDENTIFICATION

A. Title

COMSET

B. Program

PREMOD

C. Called by subroutine

PREMOD

FUNCTION

To prepare MESCOM for the BCT. The step size for MHESPOD's fixed step integration is established, the epoch values of x, y, z, $\dot{x}$, $\dot{y}$, $\dot{z}$ are preset into VSTR (NPAR), various cells are insured 0, and the type indicator for STVEC (cell DTYPE) is set to 2 to identify the initial conditions as x, y, z in case this MESCOM is placed on an ADT by MHESPOD for use as a restart in PREMOD.

USAGE

A. Calling sequence

Call COMSET

B. Input

1. COMMON

TEPOCH	Minutes from 0 hours to epoch time
NPAR	Pointer in VSTR to the current value of x_o, y_o, z_o, $\dot{x}_o$, $\dot{y}_o$, $\dot{z}_o$ for curve fit
TICRT	Value of x_o, y_o, z_o, $\dot{x}_o$, $\dot{y}_o$, $\dot{z}_o$ in earth radii and minutes

2. Calling Sequence

None

C. Output

1. COMMON

NRRR	Non-zero for fixed step Runge-Kutta
TNULL	If non-zero, the value of epoch
TB	If non-zero, the time at which to establish the search for time of rise of current satellite over Millstone Hill

TF	The maximum time interval for the length of the core ephemeris in minutes
DTYPE	Indicator for the type of initial conditions (= 1 for α δ β ARV, = 2 for x, y, z, $\dot{x}$, $\dot{y}$, $\dot{z}$, = 3 for mean elements)
TSTEP	Step size taken by TRAJ during numerical integration. Units are minutes
TLIST(3)	Current step size consistent with integration list (TLIST) and difference tables (in TRAJ)
VSTR	Variable storage
NITCT	Current iteration number for curve fit

2. Calling sequence

   None

D. Error/Action Messages

   None

SUBROUTINES USED

A. Library

   None

B. Program

TRAJ	Integrate equations of motion and variational equations
SETIC	Initialize integration list

EQUATIONS

Program sets the fixed step size for MHESPOD at twice the Runge-Kutta step chosen by TRAJ for the epoch initial conditions. The step size is not permitted to be less than 0.25 minutes.

SUBROUTINE IDENTIFICATION

A. Title

CTOM

B. Segment

PREMOD

C. Called by subroutines

PRTADT

FUNCTION

To convert a set of Cartesian elements to osculating elements and then to mean elements, at epoch time only.

USAGE

A. Calling sequence

Call CTOM(TNOMX, ADBAR, ITER)

B. Input

1. COMMON

CJ2	J2 Earth Harmonic
CMU	μ (Earth Radii, Minutes)
CPI	π
C2PI	2π
KOUT	Output tape number

2. Calling sequence

TNOMX(1)	x	Earth Radii, Minutes
TNOMX(2)	y	
TNOMX(3)	z	
TNOMX(4)	$\dot{x}$	
TNOMX(5)	$\dot{y}$	
TNOMX(6)	$\dot{z}$	
ITER	Number of iterations to be used to obtain δ's	

C. Output

1. COMMON

None

2. Calling sequence

ADBAR(1) a_{K-25_m} (Earth Radii)

ADBAR(2) e_m

ADBAR(3) i_m

ADBAR(4) Ω_m

ADBAR(5) ω_m

ADBAR(6) M_m

(ADBAR(3)–ADBAR(6): Radians)

ADBAR(7) $\dot{\omega}_m$ (Radians/Minute)

ADBAR(8) $\dot{\Omega}_m$ (Radians/Minute)

D. Error Messages

If E (eccentric anomaly) fails to converge after 50 iterations

E FAILED TO CONVERGE

THE VALUE OF E IS ±. XXXXXE ±XX

The computation proceeds with the last computed value of E.

SUBROUTINES USED

A. Library

ABS
SQRT
ATNQ
SIN
COS

B. Program

PIMOD	To set the principle value of an angle between 0 and 2π
DLSTV	To compute the δ's for conversion from osculating to mean and mean to osculating

EQUATIONS

1. Compute epoch values of

a) magnitude of radius vector

$$r_o = \sqrt{x^2 + y^2 + z^2}$$

b) Angular momentum

$$h^2_o = (y\dot{z} - z\dot{y})^2 + (z\dot{x} - x\dot{z})^2 + (x\dot{y} - y\dot{x})^2$$

c) Orbital semi-parameter

$$p_o = h_o^2/\mu$$

2. Compute osculating orbital elements.

a) Semi-major axis

$$a_{os} = r_o\mu/\left[2\mu - r_o(\dot{x}^2 + \dot{y}^2 + \dot{z}^2)\right]$$

b) Eccentricity

$$e_{os} = +\sqrt{(p_o/r_o - 1)^2 + \frac{p_o}{\mu r_o}(x\dot{x} + y\dot{y} + z\dot{z})^2}$$

c) The true anomaly v_o

$$\cos v_o = (p_o/r_o - 1)/e_{os}$$

$$\sin v_o = \left(\sqrt{p_o/r_o}\,\frac{x\dot{x} + y\dot{y} + z\dot{z}}{r_o}\right)/e_{os}$$

d) The orbital inclination and the longitude of the ascending node

$$\sin i_{os} \cos \Omega_{os} = \frac{y\dot{z} - z\dot{y}}{r_o}$$

$$\sin i_{os} \cos \Omega_{os} = \frac{x\dot{z} - z\dot{x}}{r_o}$$

$$\cos i_{os} = \frac{x\dot{y} - y\dot{x}}{r_o}$$

e) The argument of latitude, u, is determined from

$$\cos u_o = \frac{x}{r_o}\cos \Omega_{os} + y/r_o \sin \Omega_{os}$$

$$\sin u_o = z/(r_o \sin i_{os})$$

f) The argument of perigee

$$\omega_{os} = u_o - v_o$$

g) The eccentric anomaly

$$\sin E_o = [(x\dot{x} + y\dot{y} + z\dot{z})/\mu a_{os}]/e_{os}$$

$$\cos E_o = (1 - r_o/a_{os})/e_{os}$$

h) The mean anomaly

$$M_{os} = E_o - \frac{1}{\mu a_{os}}(x\dot{x} + y\dot{y} + z\dot{z})$$

Compute the initial K-25 element where $A_2 = 3/2\ J_o a_e^2$

$$a_{os_{K-25}} = a_{os}\left[1 - A_2/p_o^2\left(1 - 3/2 \sin^2 i_{os}\right)\left(1 - e_{os}^2\right)^{1/2}\right]$$

Compute the initial K-25 p

$$p_o = a_{os_{K-25}}\left(1 - e_{os}^2\right)$$

Then iterate on the following index, k

$$a_{K-25_k} = a_k\left[1 - \frac{A_2}{p_{k-1}^2}\left(1 - 3/2 \sin i_k^2\right)\left(1 - e_k^2\right)^{1/2}\right]$$

$$p_k = a_{K-25_k}\left(1 - e_k^2\right)$$

Compute δ's using $(a_{K-25_k}, e_k, i_k, \Omega_k, \omega_k, M_k)$

Compute

$$a_k = a_{os} - \delta_{a_k}$$

$$e_k = e_{os} - \delta_{e_k}$$

$$i_k = i_{os} - \delta_{i_k}$$

$$\Omega_k = \Omega_{os} - \delta_{\Omega_k}$$

$$\omega_k = \omega_{os} - \delta_{\omega_k}$$

$$M_k = M_{os} - \delta_{M_k}$$

$r = r_o$, Iterate Kepler's equations (see MTOC) to find E and v after each iteration. After the last iteration, the mean values are:

$$a_{K-25_m} = a_{K-25_k}$$

$$e_m = e_k$$

$$i_m = i_k$$

$$\Omega_m = \Omega_k$$

$$\omega_m = \omega_k$$

$$M_m = M_k$$

After iterating compute the secular rates of ω and Ω

$$\dot{\omega}_m = \frac{A_2 \sqrt{\mu}}{p^2_k} \left(2 - 5/2 \sin^2 i_k\right)$$

$$\frac{\left\{1 - \frac{A_2}{p^2_k} \left(1 - 1.5 \sin^2 i_k\right) \sqrt{1 - e^2_k}\right\}^{1/2}}{\left(a_{K-25_k}\right)^{3/2}}$$

$$\Omega_m = \frac{\sqrt{\mu A_2}}{p^2_k} \cos i_k \frac{1 - \frac{A_2}{p_k} \left(1 - 3/2 \sin^2 i_k\right) \sqrt{1 - e^2_k}}{\left(a_{K-25_k}\right)^{3/2}}$$

SUBROUTINE IDENTIFICATION

A. Title

DAPNTP

B. Segment

DAP

C. Called by subroutine

DAP

FUNCTION

The function is to interpolate the core ephemeris at a giventime. The interpolation may be for R, A, E, $\dot{R}$, $\dot{A}$, $\dot{E}$, or R, A, E, $\partial R/\partial t$, $\partial A/\partial t$, $\partial E/\partial t$.

USAGE

A. Calling sequence

CALL DAPNTP

B. Input

1. COMMON

/CE/CE(484), core ephemeris

/DAPSTR/NCEFLG, TI, R, A, E, DR, DA, DE, TI.

The time to be interpolated, minute from epoch.

2. Calling sequence

—

C. OUTPUT

1. COMMON

/DAPSTR/NCEFLG, TI, R, A, E, DR, DA, DE

NCEFLG	=	0	Interpolation occured
	=	0	Interpolation did not occur (TI was outside the core ephemeris interval)
R			Range
A			Azimuth
E			Elevation
DR			R or $\partial R/\partial t$

DA A or $\partial A/\partial t$

DE E or $\partial E/\partial t$

D. Error/ action messages

SUBROUTINE USED

—

EQUATIONS

$$t_n = t_i - t_o/\Delta_t$$

$$P_4 = \text{fractional part of } t_n$$

$$P_5 = P_4 + 1.0$$

$$P_6 = P_4 - 2.0$$

$$P_n = P_4 - 1.0$$

$$P_8 = P_4 \cdot P_5$$

$$P_9 = P_6 \cdot P_7$$

$$P_4 = -(P_4 \cdot P_9)/6.0$$

$$P_5 = (P_5 \cdot P_9)/2.0$$

$$P_6 = -(P_6 \cdot P_8)/2.0$$

$$P_7 = (P_7 \cdot P_8)/6.0$$

$$f_n = P_4 \cdot f_{i-1} + P_5 \cdot f_1 + P_6 \cdot f_{6+1} + P_7 \cdot f_{i+2}$$

SUBROUTINE IDENTIFICATION

A. Title

DAPOB

B. Program

PREMOD

C. Called by subroutine

PREMOD

FUNCTION

This program reads the observations prepared by DAP from the ADT, reverse sorts them in time and writes them on the BCT for use by MHESPOD as pre-epoch data.

USAGE

A. Calling sequence

Call DAPOB

B. Input

1. COMMON

TJDSAV	Value of Julian date at 0 hours of the epoch day from the current ADT being processed
KADT	Logical number of ADT
KOUT	Logical number of printed output device
TJDATE	Value of Julian date of 0 hours of the epoch day for current BCT being generated
KBCT	Logical number of BCT

2. Calling sequence

None

C. Output

1. COMMON

None

2. Calling sequence

None

D. Error/action messages

**** NO OBS ON ADT . . . ERROR.

SUBROUTINES USED

A. Library

.FWRT.	.FEFT.	EXIT	.FRLR.
.FVIO.	.FRDB.	.FWRD.	.FFIL.
.FPRN.	.FWRB.	.FBLT.	.FWLR.

B. Program

None

EQUATIONS

None

COMMENTS

As internal storage:

TEMP	50 cells to read ADT tape records into
DBUFF	600 cells to hold DAP observations for reverse sorting Room for all 60 DAP observation
NBUF	Size of observation record on BCT (50 words, 5 observations)

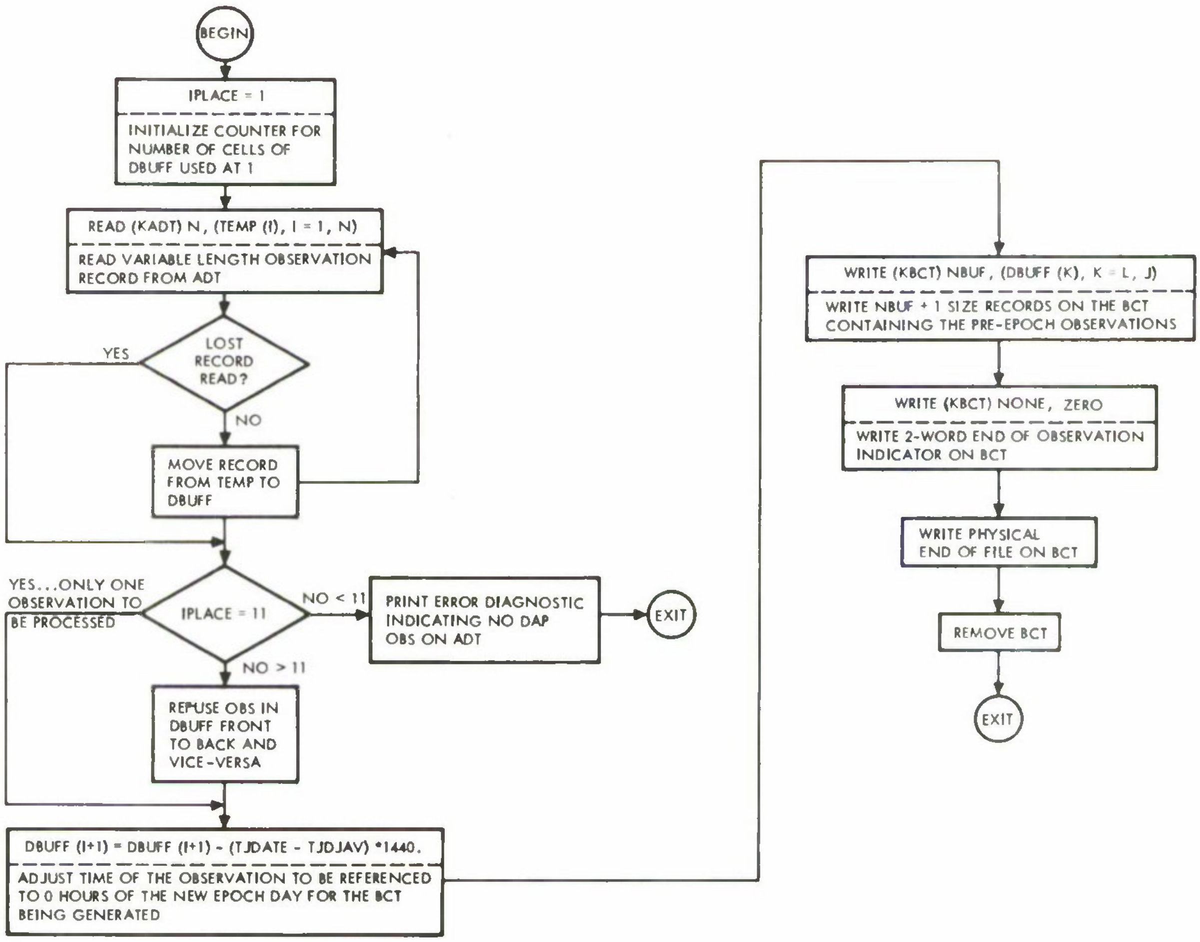


Figure 5-11. DAPOB Flow Diagram

SUBROUTINE IDENTIFICATION

A. Title

DAPRT

B. Program

PREMOD

C. Called by subroutine

PREMOD

FUNCTION

To print the data from the DAP raw-averaged observation tape. The program assumes a variable record format with word one to signify the number of words which follow in the record.

Word one = 1 . . . End of data indicator
= 16 . . . ID record
= 9 . . . Raw data point record
= 8 . . . Averaged data point record
≠ any of the above indicates an error

USAGE

A. Calling sequence

Call DAPRT

B. Input

1. COMMON

KOUT	Logical number of printed output device
KDAP	Logical number of DAP raw-averaged data tape

2. Calling sequence

None

C. Output

None

D. Error/Action Messages

If word one of any record is not a 1, 8, 9, or 16 the message:

*****ILLEGAL RECORD ON DAP TAPE

is written on KOUT.

SUBROUTINES USED

A. Library

.FVIO. .FFIL. .FCNV.
.FRDB. .FBLT.
.FWRD. .FRLR.

B. Program

None

EQUATION

None

COMMENTS

BUFF (16) is defined internally to hold the assumed largest possible record from KDAP.

SUBROUTINE IDENTIFICATION

A. Title

DAPWRT

B. Segment

MHESPØD

C. Called by subroutine

MESPØD

FUNCTIØN

Processes DAP observations to a consistent format and writes these observations on the ADT tape. Each record written on the ADT contain five observations, each of which are written in the following 10 cell format:

$$ID,\ t,\ R,\ A,\ E,\ \dot{R},\ \sigma_R,\ \sigma_A,\ \sigma_E,\ \sigma_{\dot{R}}$$

USAGE

A. Calling sequence

Call DAPWRT

B. Input

1. Labeled CØMMØN

/MESCØM/MHESPØD	CØMMØN variables
VSTR	Variable storage array
NSTAT	Starting location of the master sensor table
SIG	Sigma list for current station and associated time and observations
SIGMH	4 variable array containing σ_R, σ_A, σ_E, $\sigma_{\dot{R}}$ for Millstone Hill
/DAPBUF/	Array containing DAP observation appearing in the following format: t, R, A, E, $\dot{R}$, W (weight)

2. Calling sequence

—

C. Output

1. CØMMØN

/MESCØM/	MHESPØD CØMMØN variables
TEMP	Array of temporary storage

2. Calling sequence

—

D. Error/action messages

SUBROUTINES USED

A. Library

SQRT

B. Program

—

SUBROUTINE IDENTIFICATION

A. Title

DAUX

B. Segment

MHESPOD
PREMOD
NRTPOD

C. Called by subroutine

TRAJ
SETIC

FUNCTION

The function is to compute the second derivatives in the equations of motion and control the computation of the second derivatives in the variational equations.

USAGE

A. Calling sequence

Call DAUX

B. Input

1. COMMON

TLIST	Numerical integration working storage
SGAMAM	Constant used in calculating radiation pressure effects, $S\gamma A/m$ (e.r.^{3}/min^2)
CDAD2M	Drag parameter $C_D A/2m$ (ft^2/slug)
FLVE	Variational equation control flag, $\neq 0$, compute variational equations
TBPERT	Acceleration due to bodies (e.r./min^2)
TPOT	Acceleration due to aspherical potential (er/min^2)
TDRAG	Acceleration due to drag (e.r./min^2)
TRPRES	Acceleration due to radiation pressure (e.r./min^2)
TR	Magnitude of geocentric position vector, R(e. r.)
CMU	GM earth (e.r.^{3}/min^2)
NDPR	Total number of CATEGORY I variables to solve for

TR2	R^2
TR3	R^3
TR5	R^5
TR7	R^7

2. Calling sequence

—

C. Output

1. COMMON

TLIST (58-60) Numerical integration working storage containing the total acceleration

2. Calling sequence

—

SUBROUTINES USED

A. Library

—

B. Program

BODY
DRAG
POTENT
RADSQ
RPRESS
VAREQ

EQUATIONS

The Cowell formulation of the equations of motion is used:

$$R = \left(x^2 + y^2 + z^2\right)^{1/2}$$

$$\ddot{x} = \frac{-\mu\, x}{R^3} + \ddot{x}_{\text{bodies}} + \ddot{x}_{\text{drag}} + \ddot{x}_{\text{potential}} + \ddot{x}_{\text{radiation pressure}}$$

$$\ddot{y} = \frac{-\mu\, y}{R^3} + \ddot{y}_{\text{bodies}} + \ddot{y}_{\text{drag}} + \ddot{y}_{\text{potential}} + \ddot{y}_{\text{radiation pressure}}$$

$$\ddot{z} = \frac{-\mu\, z}{R^3} + \ddot{z}_{\text{bodies}} + \ddot{z}_{\text{drag}} + \ddot{z}_{\text{potential}} + \ddot{z}_{\text{radiation pressure}}$$

DAUX

where

$\ddot{x}_{bodies}$ = The perturbation acceleration due to other bodies in the solar system

$\ddot{x}_{drag}$ = The perturbation acceleration due to atmosphere drag

$\ddot{x}_{potential}$ = The perturbation acceleration due to the potential field set by the aspherical earth

$\ddot{x}_{radiation\ pressure}$ = The perturbation acceleration due to solar radiation pressure

The tests are made to see which of the above perturbation effects are to be included in the evaluation of the equations of motion.

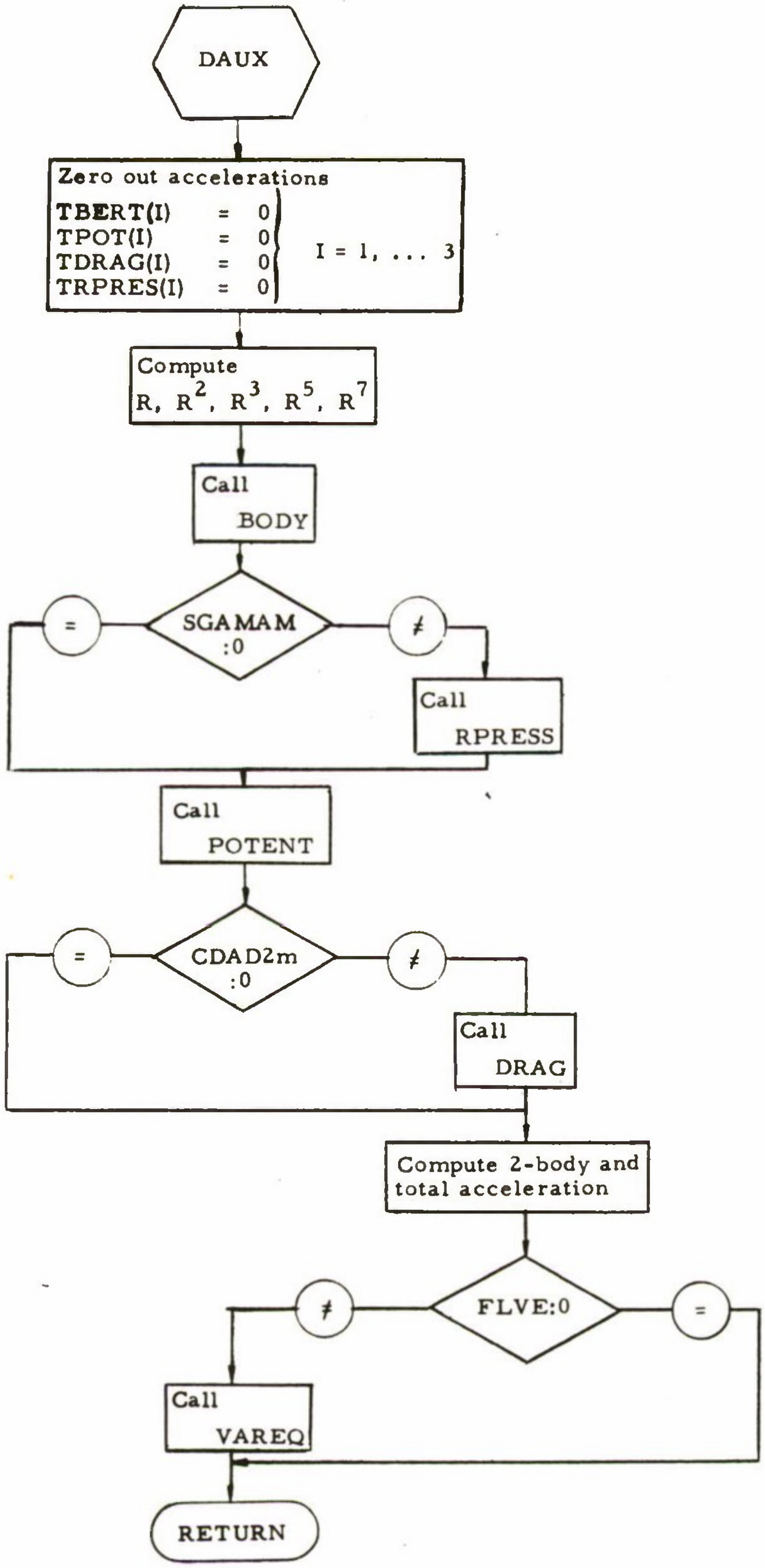


Figure 5-12. DAUX Flow Diagram

SUBROUTINE IDENTIFICATION

A. Title

DCITER

B. Segment

NRTPOD partials - least square

C. Called by subroutines

TRJPRO

FUNCTION

DCITER drives the routines which compute the normal matrix from observations and the trajectory and which do one iteration of the differential correction. Convergence is monitored in DCITER.

USAGE

A. Calling sequence

Call DCITER

B. Input

1. COMMON

BYPASS IFLAG SKIPC	Flags to control rewinding of observation tape
KOUT	Peripheral output tape
MT	Observation tape
ITRJTP	Intermediate trajectory tape
DCFLG(10)	Differential correction flags from JDC card, (cc 41 - 50)
PSTFLG(10)	Post-processor flags from JDC card (cc 51 - 60)
DTMAX	Days from epoch after which observations will not be accepted (provided at input)
TEPOCH	Time in minutes from midnight day of epoch to epoch

IFTEX	Flag to indicate convergence or non-convergence conditions
TG	Observation time (minutes from midnight day of epoch) at which the trajectory tape has been written
TCRASH	Flag returned by TRJGET to indicate impact
TUBSEF	Flag to signal end of observation processing
PLSTSN	Current sensor number
PUBS (8)	Current observation date

2. Calling sequence

—

C. Output

1. COMMON

BYPASS IFLAG SKIPC	See B. 1
COUNT	Lines counter to control output format
IPFRST	First time flag for RADR

2. Calling sequence

—

3. Convergence - no convergence messages

SUBROUTINES USED

1. Program

FIT
LINES
PARSET
PRSSTB
RADR
REJECT
TRJGET
UBSGET

2. Library

.FBLT.
.FFIL.
.FRWT.
.FVIO.
.FWLR.
.FWRB.
.FWRD.
.FXEM.

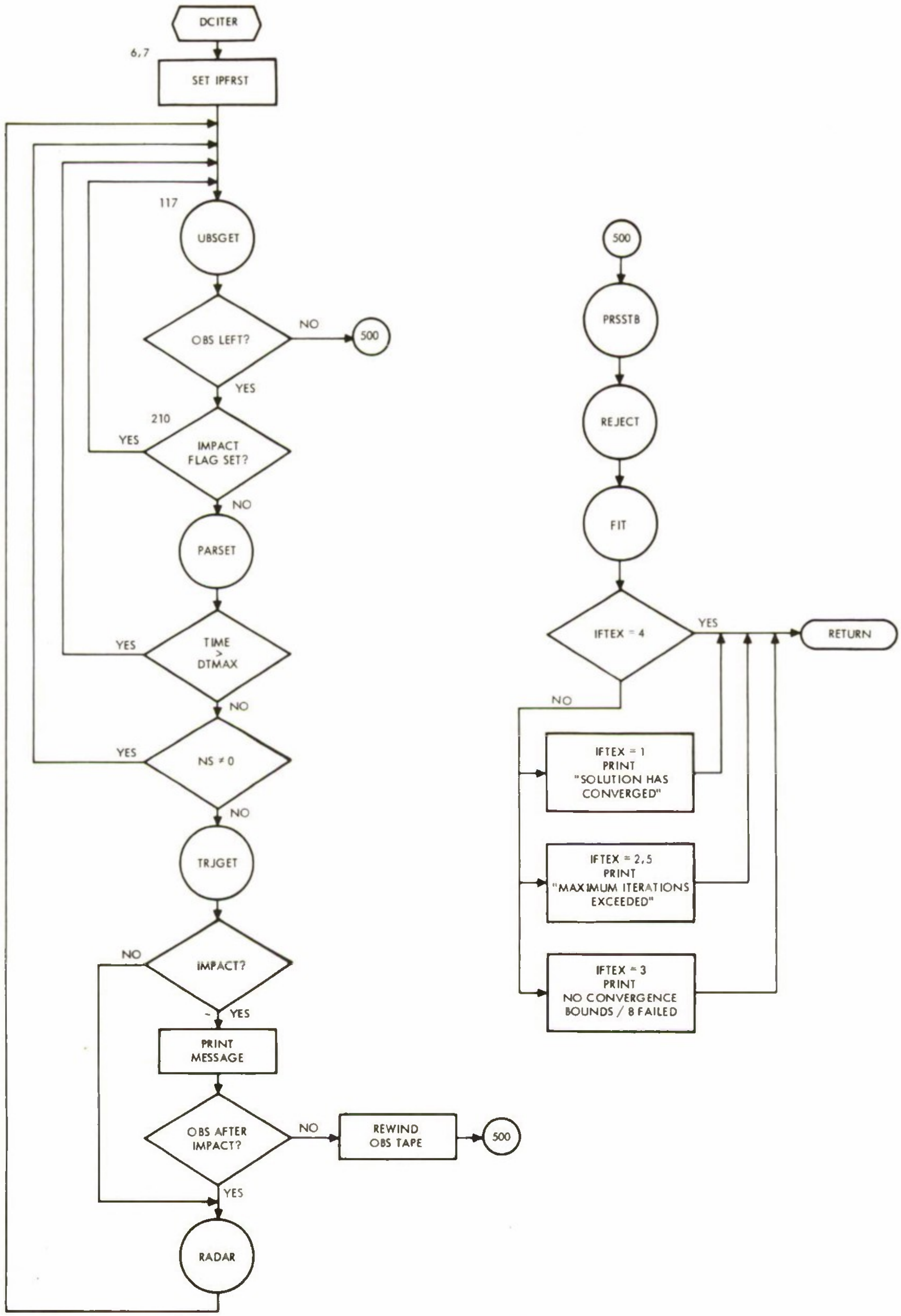


Figure 5-13. DCITER Flow Diagram

SUBROUTINE IDENTIFICATION

A. Title
DLSTV

B. Segment
PREMOD

C. Called by subroutines
MTOC and CTOM

FUNCTION

To compute the differentials used to convert from osculating to mean and mean to osculating.

USAGE

A. Calling sequence
Call DLSTV (STATE, R, V, E, DELTA)

B. Input

1. COMMON

CJ2 J2 Earth Harmonic

2. Calling sequence

	Osculating	or	Mean	
STATE(1)	$a_{o_{K-25}}$		$a_{m_{K-25}}$	(Earth Radii)
STATE(2)	e_o		e_m	
STATE(3)	i_o		i_m	(Radians)
STATE(4)	Ω_o		Ω_m	(Radians)
STATE(5)	ω_o		ω_m	(Radians)
STATE(6)	M_o		M_m	(Radians)
R	Magnitude of radius vector			(Earth Radii)
V	True anomaly			(Radians)
E	Eccentric anomaly			(Radians)

C. Output

1. COMMON

None

2. Calling sequence

DELTA(1) δ_a

DELTA(2) δ_e

DELTA(3) δ_i

DELTA(4) δ_Ω

DELTA(5) δ_ω

DELTA(6) δ_M

DELTA(7) $\delta\,(\omega + M)$

D. Error Messages

None

SUBROUTINES USED

A. Library

SIN
COS
SQRT

B. Program

None

EQUATIONS

Equations (2), (5), and (6) have been formulated to preserve numerical accuracy when eccentricity is near zero, and hence do not appear as in the standard references, Kozai, et al.

$$da = \frac{A_2}{a}\frac{2}{3}\left[\left(1 - \frac{3}{2}\sin^2 i\right)\left\{\left(\frac{a}{r}\right)^3 - \left(1 - e^2\right)^{-3/2}\right\} + \left(\frac{a}{r}\right)^3 \sin^2 i \cos 2(v + \omega)\right] \tag{1}$$

$$de = \frac{A_2}{a^2}\left\{(1 - e^2)\left[\frac{1}{3}\left(1 - \frac{3}{2}\sin^2 i\right)(S_5 - S_3)\right] + \frac{\sin^2 i \cos 2u}{2} S_6 - \frac{\sin^2 i}{2(1-e^2)}\left[\cos(v + 2\omega) + \frac{1}{3}\cos(3v + 2\omega)\right]\right\} \tag{2}$$

where

$$S_1 = e/1 + (1 - e^2)^{1/2}$$

$$S_2 = S_1/(1 - S_1 e)$$

$$S_3 = 3S_2 + 3S_2^2 e + s_2^3 e^2$$

$$S_4 = \cos E/(1 - e \cos E)$$

$$S_5 = 3S_4 + 3S_4^2 e + s_4^3 e^2$$

$$S_6 = \frac{S_5 + (1 + S_5 e)(e^3 - 2e)}{1 - e^2}$$

$$di = \frac{1}{4} \frac{A_2}{P^2} \sin 2i \left\{ \cos 2 (v + \omega) + e \cos (v + 2\omega) + \frac{e}{3} \cos (3v + 2\omega) \right\} \quad (3)$$

where

$$P = a(1 - e^2)$$

$$d\Omega = \frac{A_2}{P^2} \cos i \left\{ (v - M) - \frac{1}{2} \sin 2 (v + \omega) + e \sin v - \frac{e}{2} \sin (v + 2\omega) \right.$$

$$\left. - \frac{e}{6} \sin (3v + 2\omega) \right\} \quad (4)$$

$$d\omega = \frac{A_2}{P^2} A(e^{-1}) + B(e^o) + C(e^1)$$

where

$$A(e^{-1}) = \frac{1}{12e} [12 \sin v + \sin^2 i \{7 \sin (3v + 2\omega) - 18 \sin v$$

$$- 3 \sin (v + 2\omega)\}]$$

$$B(e^o) = \frac{1}{8} [16 (v - M) + 4 \sin 2v - 4 \sin 2(v + \omega) + \sin^2 i \{10 \sin 2(v + \omega)$$

$$+ 3 \sin (4v + 2\omega) - 20 (v - M) - 6 \sin 2v\}]$$

$$C(e^1) = \frac{e}{48}\left[12\left(7 \sin v + \frac{\sin 3v}{3}\right) - 24 \sin (v + 2\omega) - 8 \sin (3v + 2\omega)\right.$$

$$+ \sin^2 i \{19 \sin (3v + 2\omega) + 3 \sin (5v + 2\omega) + 3 \sin (v - 2\omega)$$

$$\left. + 45 \sin (v + 2\omega) - 6 (17 \sin v + \sin 3 v)\}\right]$$

$$dM = \frac{A_2}{P^2} \sqrt{1 - e^2} [A(e^{-1}) + B(e^{o}) + C(e^1)] \tag{6}$$

where

$$A(e^{-1}) = \frac{1}{12e} [- 12 \sin v + \sin^2 i \{18 \sin v + 3 \sin (v + 2\omega)$$

$$- 7 \sin (3v + 2\omega)\}]$$

$$B(e^{o}) = + \frac{1}{8} [- 4 \sin 2v + 3 \sin^2 i \{2 \sin 2 v - \sin (4v + 2\omega)\}]$$

$$C(e^1) = \frac{e}{48} [12 \sin v - 4 \sin 3v + \sin^2 i \{- 18 \sin v + 6 \sin 3v$$

$$+ 15 \sin (v + 2\omega) - 3 \sin (v - 2\omega) + \sin (3v + 2\omega)$$

$$- 3 \sin (5v + 2\omega)\}]$$

SUBROUTINE IDENTIFICATION

A. Title

DOBPRT

B. Program

PREMOD

C. Called by subroutine

PRTADT

FUNCTION

To print the DAP observations recorded on the ADT. When this routine is executed, the ADT tape is assumed positioned at the first DAP record.

USAGE

A. Calling sequence

CALL DOBPRT

B. Input

1. COMMON

TEMP	Temporary storage
KADT	Logical number of ADT tape
NDAPOB	Number of observations from DAP used in curve fit
KOUT	Logical number of printed output device
CKMER	Kilometers per earth radius
CDEG	Degrees per radian

2. Calling sequence

None

C. Output

None

D. Error/action messages

All DAP observations recorded on tape but not used in the MHESPOD curve fit are printed and so indicated.

SUBROUTINES USED

A Library

.FBLT.	.FRDB.	.FWRD.
.FCNV.	.FRLR.	
.FFIL.	.FVIO.	

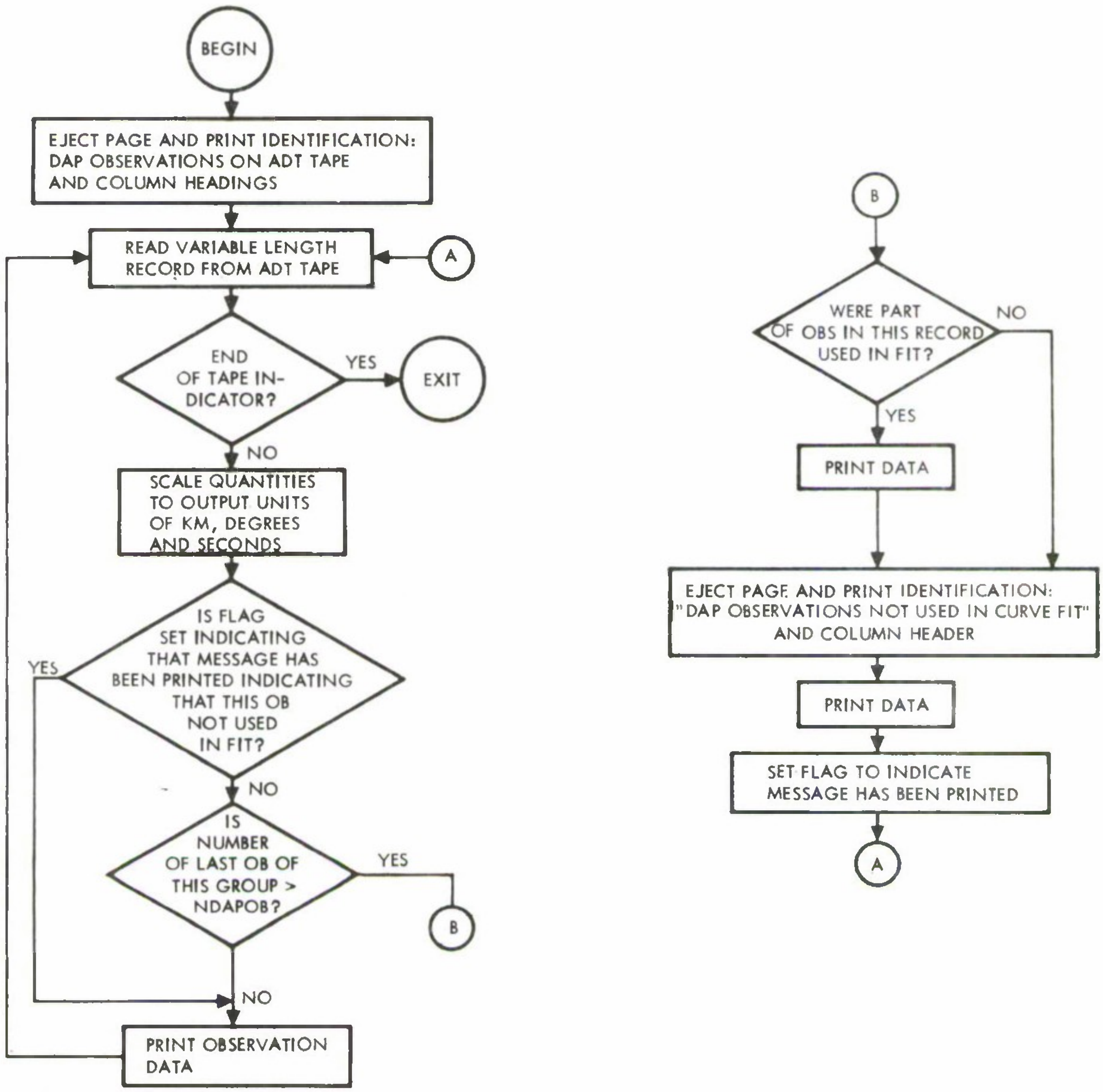


Figure 5-14. DOBPRT Flow Diagram

SUBROUTINE IDENTIFICATION

A. **Title**

DØT

B. **Segment**

MHESPOD
PREMOD
NRTPOD

C. **Called by subroutine**

—

FUNCTION

Function is to compute the scalar product C = A · B if D is non-zero; the routine stores the angle between A and B in E.

USAGE

A. Calling sequence

Call DØT (A, B, C, D, E)

B. Input

1. CØMMØN

   —

2. Calling sequence

   a) A The beginning location of a three-dimensional vector $N = (n_1, n_2, n_3)$

   b) B The beginning location of a three-dimensional vector $M = (m_1, m_2, m_3)$

   c) D D = 0, do not compute angle between A and B
   D ≠ 0, do compute the angle between A and B

C. Output

1. CØMMØN

   —

2. Calling sequence

   a) C Scalar product

   b) E Angle between A and B

D. Error/action messages

—

SUBROUTINES USED

A. Library

SQRTF

B. Programs

ATNQF	Arc tangent
RADSQ	Compute R and R^2 for X, Y, Z

EQUATIONS

$$C = n_1m_1 + n_2m_2 + n_3m_3$$

$$E = \cos^{-1}\left[\frac{C}{|N|\,|M|}\right]$$

SUBROUTINE IDENTIFICATION

A. Title

DPRLM

B. Program

PREMOD

C. Called by subroutine

PREMOD

FUNCTION

Establish initial state vector in TNOMX, parameters associated with the epoch time and print the conditions.

USAGE

A. Calling sequence

CALL DPRLM

B. Input

1. COMMON

XICOND	Contents of STVEC from input.
DTYPE	Type of conditions in XICOND. (= 1 for $\alpha\ \delta\ \beta$ A X V, = 2 for x, y, z, $\dot{x}$, $\dot{y}$, $\dot{z}$, = 3 for mean elements)
CDEG	Degrees per radian

2. Calling sequence

None

C. Output

1. COMMON

TNOMX	Initial conditions at epoch $x_o\ y_o\ z_o\ \dot{x}_o\ \dot{y}_o\ \dot{z}_o$ in kilometers and seconds

2. Calling sequence

None

D. Error/action messages

None

SUBROUTINES USED

A. Library

.FVIO.	.FCNV.
.FWRD.	.FFIL.

B. Program

TINIT	Converts time to integral year, month, day, hour, minute and second, calculates αg_o and epoch time in minutes from 0 hours
IPRNT	Prints initial conditions, time and αg_o
PTOC	Converts $\alpha\delta\beta\rho$ ARV to $xyz\dot{x}\dot{y}\dot{z}$
MTOC	Converts mean elements to $xyz\dot{x}\dot{y}\dot{z}$ and updates

EQUATIONS

None

COMMENTS

The header message:

PRELIMINARY INITIAL CONDITIONS AT TOLD or TNULL

is printed here.

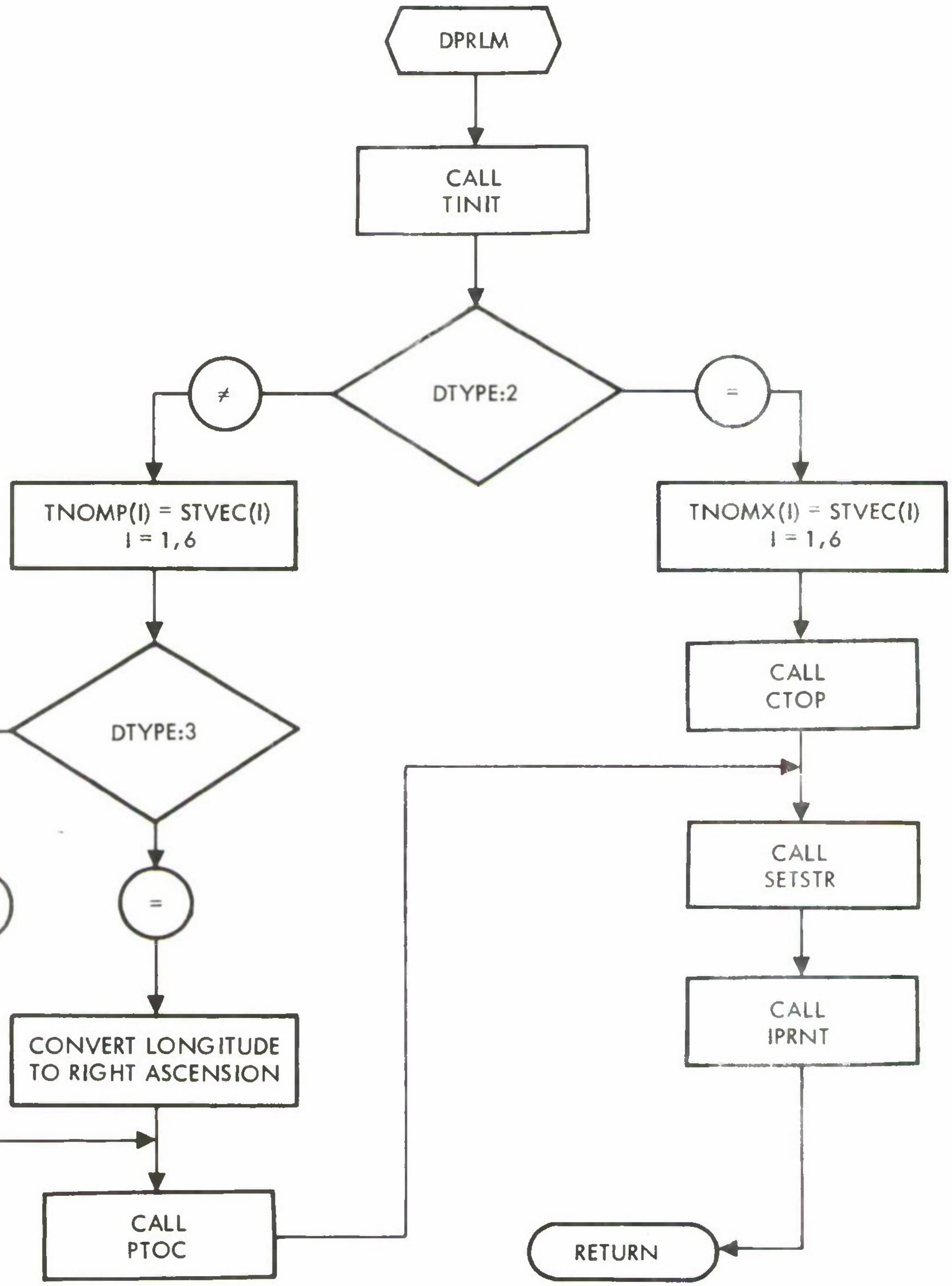


Figure 5-15. DPRLM Flow Diagram

SUBROUTINE IDENTIFICATION

A. Title

DPRLM

B. Segment

NRTPOD - Input Processor

C. Called by subroutine

INPUT

FUNCTION

To set up preliminary information for the input processor link. This information concerns epoch time and mode of epoch position and velocity.

USAGE

A. Calling sequence

Call DPRLM

B. Input

1. COMMON

CDEG	Degrees/radian
CWE	Earth's rotational rate (radians/min)
STVEC	Input initial conditions
DTYPE	Initial conditions type

2. Calling sequence

—

C. Output

1. COMMON

TALFAG	αg for midnight day of epoch
TEPOCH	Epoch time, minutes from midnight
TNOMX	Initial Cartesian coordinates
TNOMP	Initial spherical coordinates

2. Calling sequence

—

D. Error/action messages

—

SUBROUTINES USED

A. Library

—

B. Program

TINIT	Sets up initial time, computes αg and DBASE (days from 1950 to day of epoch)
PIMOD	Takes principle value of angle between 0 and 2π
PTOC	Converts from polar coordinates to Cartesian coordinates
CTOP	Converts Cartesian coordinates to polar coordinates
SETSTR	Sets up drag, radiation pressure, potential, parameters
IPRNT	Prints header page

SUBROUTINE IDENTIFICATION

A. Title

DPROS

B. Segment

NRTPOD Input processor

C. Called by subroutine

INPUT

FUNCTION

To issue calls on the sensor and observation loading routines if required by input.

USAGE

A. Calling sequence

CALL DPROS

B. Input

1. COMMON

PREFLG	NRTPOD control flags (JDC columns 31-40)
MT	Logical unit for the observation tape

2. Calling sequence

-

C. Output

1. COMMON

—

2. Calling sequence

—

D. Error/action messages

—

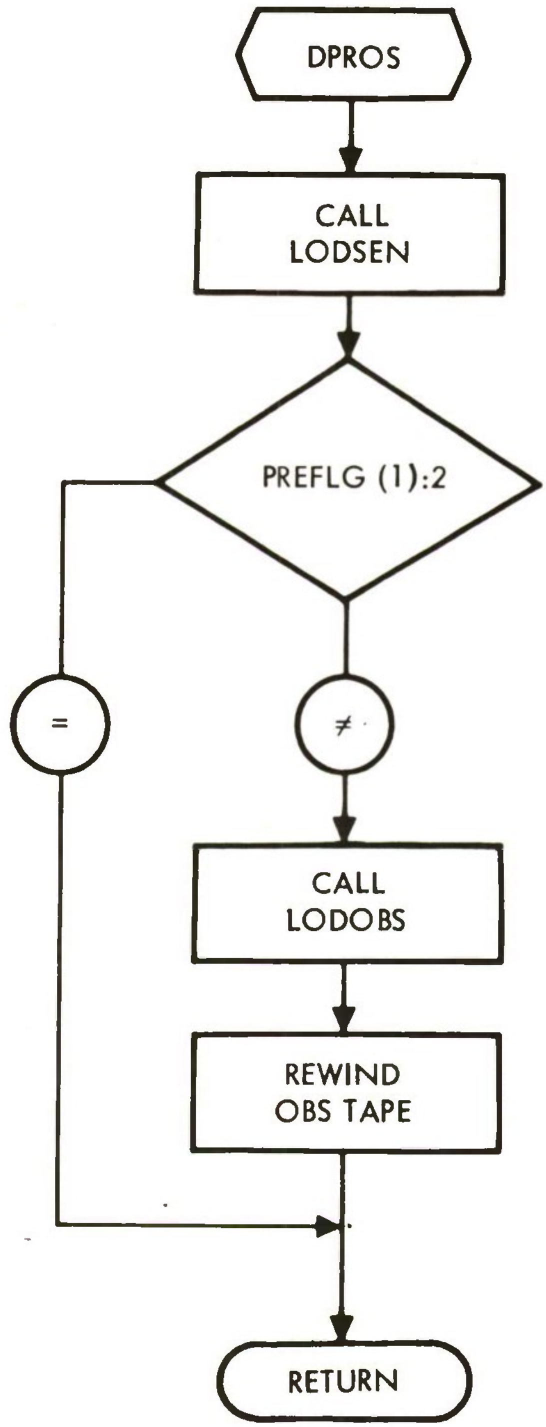


Figure 5-16. DPROS Flow Diagram

SUBROUTINE IDENTIFICATION

A. Title

DRDP

B. Segment

MHESPOD
NRTPOD

C. Called by subroutine

RADR

FUNCTION

Function is to compute the partial of the M^{th} type of observation with respect to the solution vector.

USAGE

A. Calling sequence

Call DRDP (M)

B. Input

1. COMMON

NAROW	Starting location where one row of the augmented matrix (A, B) is stored
NDPR	Number of all differential plus initial parameters to solve for (Category 1)
PCSA	Cos A
PRSUB1	R_1 = VR
PSNA	Sin A
PSNE	Sin E
PSTAT	Working storage for sensor information
PUDTI	$\dot{u} = (\dot{u}_1, \dot{u}_2, \dot{u}_3)$
PUI	(u_1, u_2, u_3)
PWDTPP	$\partial\dot{w}/\partial P_i$
PWPP	$\partial w/\partial P_i$

2. Calling sequence

M Observation type number (1, 2, 3, 4,)

C. Output

1. COMMON

VSTR(NAROW) - VSTR(NAROW + NDPR-1) contains the partial derivatives of the M^{th} type observation with respect to the Category 1 variables being solved for

2. Calling sequence

—

SUBROUTINES USED

A. Library

B. Program

—

EQUATIONS

Range (type 1 observation)

$$\frac{\partial R}{\partial p_i} = u_1 \frac{\partial w_1}{\partial p_i} + u_2 \frac{\partial w_2}{\partial p_i} + u_3 \frac{\partial w_3}{\partial p_i} \qquad p_i \rightarrow x,\ y,\ z,\ \dot{x},\ \dot{y},\ \dot{z}$$

Azimuth (type 2 observation)

$$\frac{\partial A}{\partial p_i} = \frac{1}{R_1}\left[\frac{\partial w_2}{\partial p_i}\cos A - \left(\frac{\partial w_1}{\partial p_i}\sin \phi^* + \frac{\partial w_3}{\partial p_i}\cos \phi^*\right)\sin A\right]$$

Elevation (type 3 observation

$$\frac{\partial E}{\partial p_i} = \frac{1}{R_1}\left(\frac{\partial w_1}{\partial p_i}\cos \phi^* + \frac{\partial w_3}{\partial p_i}\sin \phi^* - \frac{\partial R}{\partial p_i}\sin E\right)$$

Range Rate (type 4 observation)

$$\frac{\partial \dot{R}}{\partial p_i} = \left(\frac{\partial \overline{w}}{\partial p_i} \cdot \dot{\overline{u}}\right) + \left(\overline{u} \cdot \frac{\partial \dot{\overline{w}}}{\partial p_i}\right)$$

SUBROUTINE IDENTIFICATION

A. Title

DRAG

B. Segment

MHESPOD
PREMOD
NRTPOD

C. Called by subroutine

DAUX

FUNCTION

Function is to compute the perturbative acceleration of a vehicle due to atmosphere drag and to account for these effects in the variational equations.

USAGE

A. Calling sequence

Call DRAG

B. Input

1. COMMON

FLVE	Variational equation control flag
TV	Earth-fixed velocity of vehicle
TVA	Magnitude of TV
CELLIP	Constant = ellipticity of the Earth
TLIST	Numerical integration working storage
TR2	Square of TR
TR	Magnitude of the vector from the center of the Earth to the vehicle
CWE	Constant = rotation rate of the earth (radians/minutes) = ω_e
CDAD2M	Drag parameters $C_D A/2m$
CFTER	Feet per earth radius
TRHOA	Density in slugs/ft^3
TALT	Altitude of vehicle in feet

2. Calling sequence

—

C. Output

1. COMMON

TDRAG	Perturbative acceleration due to drag
VMAT	Matrix of velocity dependent terms in the evaluation of the variational equations
PMAT	Matrix of position dependent terms in the evaluation of the variational equation. (The drag effects are added to the contents of this matrix.)

D. Error/action messages

—

SUBROUTINES USED

A. Library

SQRT

B. Program

JACHIA

OUTER

EQUATIONS

$$R_e = \frac{1 - \epsilon}{\left[1 - \epsilon(2 - \epsilon)\left(\frac{x^2 + y^2}{R^2}\right)\right]^{1/2}} = \text{radius of the Earth}$$

$$\text{Altitude} = R - R_e$$

$$\rho_a = \text{density at the given altitude}$$

$$v_{ax} = \dot{x} + \omega_e y$$

$$v_{ay} = \dot{y} - \omega_e x \qquad \text{Earth-fixed velocity}$$

$$v_{az} = \dot{z}$$

$$v_a = \left(v_{ax}^2 + v_{ax}^2 + v_{ax}^2\right)^{1/2}$$

$$\lambda = \frac{C_d A}{2m} + TD\emptyset N \cdot K$$

$$\ddot{z}_{drag} = -\rho_a \cdot V_a \cdot \lambda \cdot v_{ax}$$

$$\ddot{y}_{drag} = -\rho_a \cdot V_a \cdot \lambda \cdot v_{ay}$$

$$\ddot{z}_{drag} = -\rho_a \cdot V_a \cdot \lambda \cdot v_{az}$$

DRAG

$$PMAT = PMAT - \lambda\rho_a v_a \begin{bmatrix} 0 & \omega_e & 0 \\ -\omega_e & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} - \frac{\lambda V_a \rho'}{R} \begin{bmatrix} v_{ax}x & v_{ax}y & v_{ax}z \\ v_{ay}x & v_{ay}y & v_{ay}z \\ v_{az}x & v_{az}y & v_{az}z \end{bmatrix}$$

$$- \frac{\lambda\rho_a}{V_a} \begin{bmatrix} v_{ax}^2 & v_{ax}v_{ay} & v_{az}v_{az} \\ v_{ax}v_{ay} & v_{ay}^2 & v_{ay}v_{az} \\ v_{ax}v_{az} & v_{ay}v_{az} & v_{az}^2 \end{bmatrix} \begin{bmatrix} 0 & \omega_e & 0 \\ -\omega_e & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

$$VMAT = VMAT - \frac{\lambda\rho_a}{V_a} \begin{bmatrix} v_{ax}^2 & v_{ax}v_{ay} & v_{ax}v_{ax} \\ v_{ax}v_{ay} & v_{ay}^2 & v_{ay}v_{az} \\ v_{ax}v_{az} & v_{ay}v_{az} & v_{az}^2 \end{bmatrix} - \lambda\rho_a v_a \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

SUBROUTINE IDENTIFICATION

A. Title

EVERT

B. Segment

MHESPOD
NRTPOD
PREMOD

C. Called by subroutines

BODY
RPRESS

FUNCTION

Using Everett's Interpolation formula, this routine approximates the positions of the moon and sun as a function of a given time. Required input are positions of the moon and sun along with their second and fourth differences at daily intervals.

USAGE

A. Calling sequence

CALL EVERT (TT)

B. Input

1. COMMON

XJD	Away of Julian dates (mod 2430000.)
POS	Position array (moon and sun) corresponding to XJD (true of date)
DEL2	Array of 2nd central differences of position corresponding to XJD (true of date)
DEL4	Array of 4th central differences of position corresponding to XJD (true of date)
TEMP	Temporary storage

2. Calling sequence

TT	Interpolation argument - time (days mod 2430000.)

C. Output

1. COMMON

XN — 6-cell array containing positions of the moon and sun

$XN(1) = X_{moon}$

$XN(2) = Y_{moon}$

$XN(3) = Z_{moon}$

$XN(4) = X_{sun}$

$XN(5) = Y_{sun}$

$XN(6) = Z_{sun}$

2. Calling sequence

—

D. Error/action meassages

—

SUBROUTINES USED

A. Library

—

B. Program

—

EQUATIONS

Everett's Interpolation formula using central differences

$$f_o = f(x_o)$$

$$f_1 = f(x_1)$$

$$h = x_1 - x_o$$

$$u = \frac{x - x_o}{h}$$

$$v = \frac{x_1 - x}{h}$$

EVERT

$$f(x) = v\, f_o + \frac{v\,(v^2-1)}{3!}\,\delta^2 f_o + \frac{v(v^2-1)\,(v^2-4)}{5!}\,\delta^4 f_o$$

$$+ u f_1 + \frac{u(u^2-1)}{3!}\,\delta^2 f_1 + \frac{u(u^2-1)\,(u^2-4)}{5!}\,\delta^4 f_1$$

SUBROUTINE IDENTIFICATION

A. Title

FIT

B. Segment

MHESPØD

C. Called by subroutine

MESPØD

FUNCTION

This subroutine monitors the solution of the normal equations, the application of the solution vector, and the iteration control.

USAGE

A. Calling sequence

Call FIT

B. Input

1. CØMMØN

IFTEX	Indicates mode of exit from FIT
NDPAR1	Starting location where the solution vector will be stored
NITCT	Iteration counter
NITER	Maximum iterations allowable in ESPØDDC
PØBCNT	Number of observations actually included on any iteration
TEMP	Temporary storage
TSUS	Current RMS
TSUSP	Predicted RMS for next iteration

2. Calling sequence

—

C. Output

1. CØMMØN

VSTR	Array in variable storage containing the set of bounds to be used on the next iteration

2. Calling sequence

—

SUBROUTINES USED

A. Library

SQRT

B. Program

APPLY	Applies DC solution vector and prints
LEGS2	Least squares package, solves AX = B

EQUATIONS

—

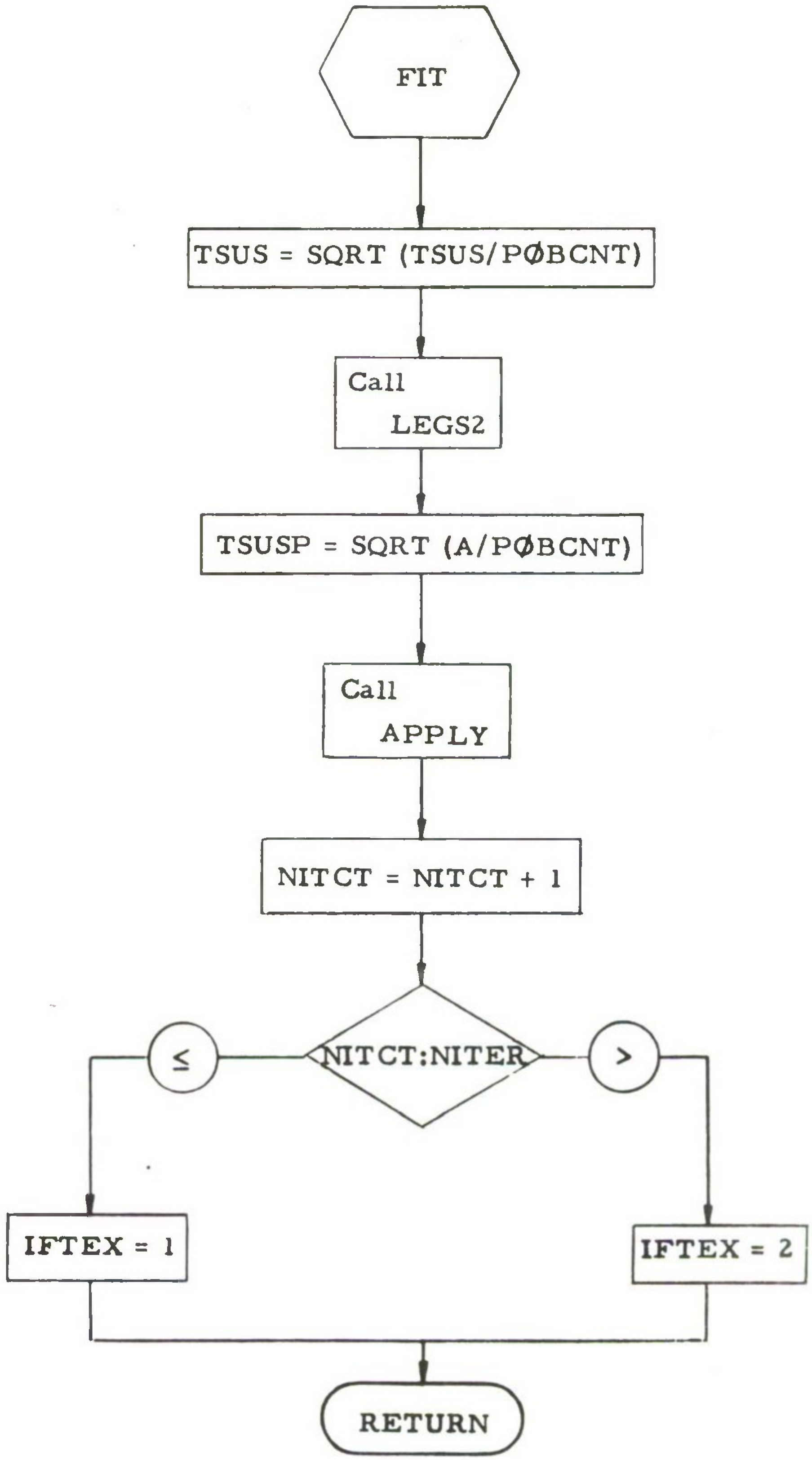


Figure 5-17. FIT Flow Diagram

SUBROUTINE IDENTIFICATION

A. Title

FIT

B. Segment

NRTPOD

C. Called by subroutine

DCITER

FUNCTION

This subroutine monitors the flow of information through the following sequence of events.

a) Determines whether the current iteration is converging or diverging

b) Forming the solution vector of the differential correction and applying it to give new estimates of the parameters being solved for

c) Test for maximum iterations

d) Set the bounds for the next iteration

e) Test whether 4 solutions in a row have failed to converge

USAGE

A. Calling sequence

CALL FIT

B. Input

1. COMMON

CFTEPS	Convergence criterion, (nominally set to 1. 0 E-3).
KOUT	Symbolic output tape (print).
NDPAR1	Identifier showing the starting location of where the solution vector will be stored in variable storage.
NPR	Total number of parameters to solve for.
NITER	Maximum allowable iterations.
IFIT	Identifies predicted RMS's if bounds are used in forming solutions.
CFLAG	Suppresses RMS test when impact has occurred.

NITCT	Counter on number of iterations.
TSUSB	Best RMS so far.
TSUSP	Predicted RMS for next iteration.
TZ	Flag to indicate if the solution was affected by the bounds. If the flag is non-zero the solution was affected by the bounds.
XBSQ	Scale factor for BNDS to cause subsequent solutions to be affected by bounds.
TCRASH	Flag to indicate impact, TCRASH $\neq 0$, indicates impact has occurred.
IFTEX	Indicates mode of exit from FIT.
POBCNT	Number of observables actually included (after editing, etc.) on any iteration.
TSUS	Current RMS.

2. Calling sequence

-

C. Output

1. COMMON

VSTR (NBDNS)	Array in variable storage containing the set of bounds to be used on the next iteration

2. Calling sequence

-

D. Error/action messages

"*************MAJOR PROGRAM ERROR....POSSIBLE INPUT AND/OR MACHINE ERROR"

This message is printed if IFIT is less than or equal to zero.

SUBROUTINES USED

A. Library

SQRT
ABS

B. Program

BOUNDS	Scale bounds with a given scale factor
LEGS2	Least square package, solves Ax = B
APPLY	Applies differential correction solution vector and prints the iteration summary.

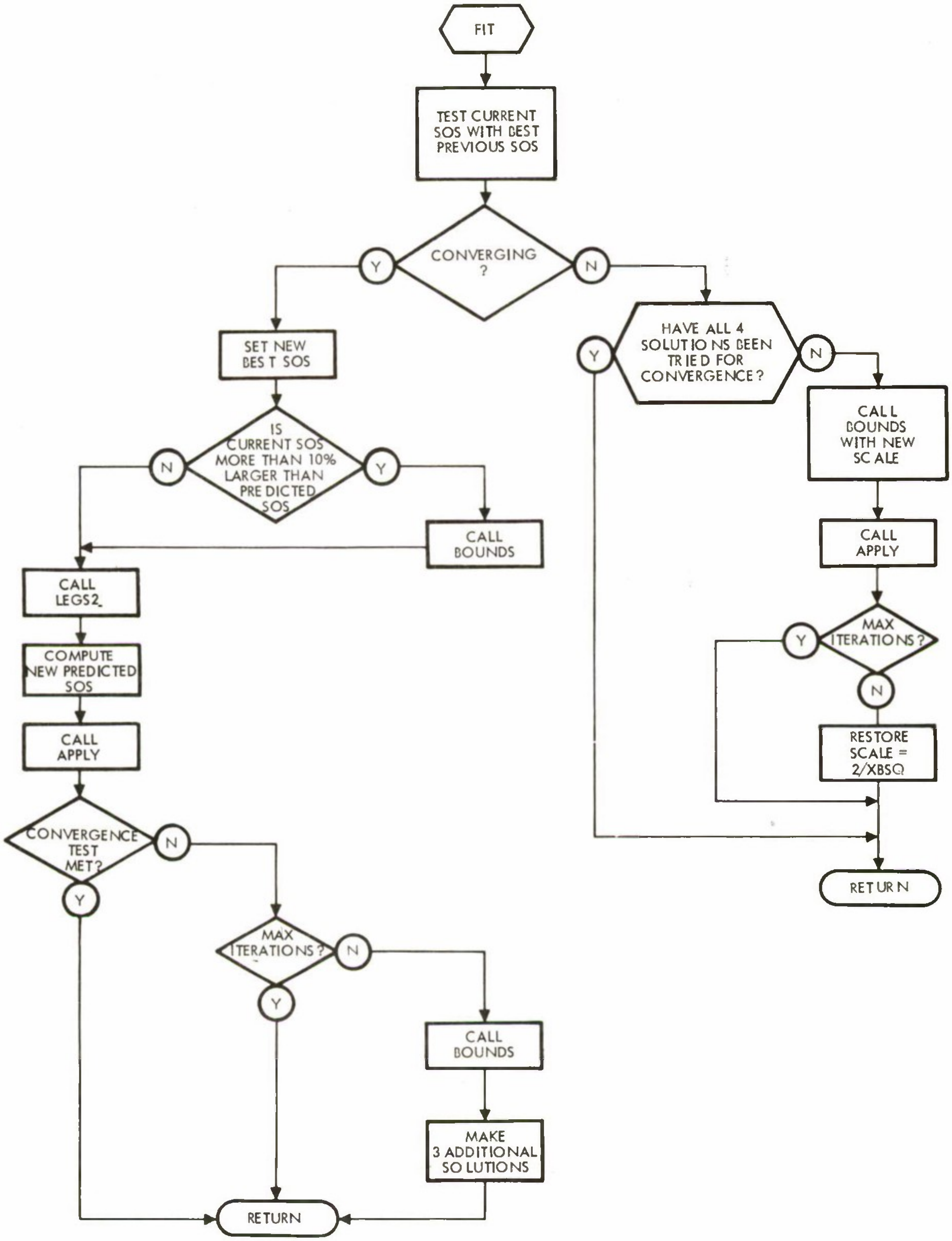


Figure 5-18. FIT Flow Diagram

SUBROUTINE IDENTIFICATION

A. Title

GENCE

B. Segment

PREMOD

C. Called by subroutine

PREMOD

FUNCTION

To generate the core ephemeris. The ephemeris is placed in /CE/ and its contents are printed on unit KOUT.

USAGE

A. Calling sequence

Call GENCE

B. Input

1. COMMON

TNODE	Final time, in minutes from 0 hours, to be considered in the core ephemeris
TEPOCH	Time, in minutes from 0 hours, of epoch, the time of the initial conditions of the trajectory
CEP1	A parameter to control the interval of the core ephemeris. The interval will be integer multiple of 60/CEP1 seconds
KOUT	Number of the output device
NSTAT	Location in VSTR of the first cell of the master sensor table
VSTR	Block of "variable storage"
CKMER	Kilometers per earth radius
CDEG	Degrees per radian
ICEFLG	Core ephemeris flag: = O if $\frac{\partial R}{\partial t}$, $\frac{\partial A}{\partial t}$, $\frac{\partial E}{\partial t}$ desired = 1 if $\dot{R}$, $\dot{A}$, $\dot{E}$ desired

2. Calling sequence

—

C. Output

1. COMMON

/CE/	The core ephemeris

2. Calling sequence

—

D. Error/ action messages

-

E. Internal storage

1. COMMON

PSTAT	The working station table
PUBS	The observation table

2. Temporary storage

CESIZ	The number of entries in the core ephemeris
TEMP	Temporary storage
ICE	A working counter pointing to the next time entry in the core ephemeris
I, J, L	Counters for DO loops
XI	Floating point value of I counter for use in REAL arithmetic statement

SUBROUTINES USED

A. Library

. FCNV.	. FVIO.
. FFIL.	. FWRD.

B. Program

CEAZ	Insures a smooth azimuth in the core ephemeris
CEGEN	Generates R, A, E, $\dot{R}$, $\dot{A}$, $\dot{E}$, $\ddot{R}$, $\frac{\partial R}{\partial t}$, $\frac{\partial A}{\partial t}$, $\frac{\partial E}{\partial t}$ at time t
SETIC	Initialize integration routine
TRAJ	Integrates the equations of motion

EQUATIONS

The Δ time interval for the core ephemeris is computed in the following way:

Let

N = Total # of entries in the core ephemeris (CESIZ)

T_L = Final time of interest for the core ephemeris (TNODE)

T_o = Initial time for the trajectory simulation (TEPOCH)

K = Δ must be a multiple of $\frac{60}{K}$ seconds. For example:

if $K = 1$ . . . Δ must be a multiple of 1 minute
$K = 30$ . . . Δ must be a multiple of .5 minute
$K = 60$ . . . Δ must be a multiple of 1 second

Since the interpolation scheme requires 4 points, 2 in front and 2 behind, we must ensure that there are 2 entries in the core ephemeris beyond T_L or:

T_o — $T_o + \Delta$ — $T_o + (N-3)\Delta$ — T_L — $T_o + (N-2)\Delta$ — $T_o + (N-1)\Delta$

or

$T_L < T_o + (N-2)\,\Delta$ or $T_L = T_o + (N-3)\,\Delta$

$$\Rightarrow \Delta_{min} = \frac{T_L - T_o}{N-3}$$

to insure Δ is a multiple of 60/K seconds:

$Q = \left[K\,\Delta_{min}\right]$ where $[x]$ = integer part of x

$\Delta = QK.$

SUBROUTINE IDENTIFICATION

A. Title

GPERT

B. Segment

MHESPOD
PREMOD
NRTPOD

C. Called by subroutine

POTENT

FUNCTION

The function of this subroutine is computing the perturbative acceleration of a spacecraft resulting from the fact that the Earth is not a homogeneous sphere. (The resulting harmonics are termed zonal, sectorial, and tesseral.)

USAGE

A. Calling sequence

Call GPERT

B. Input

1. COMMON

SIPH	Sin ϕ where ϕ is the geocentric latitude of the vehicle
COPH	Cos ϕ
SILA	Sin λ where λ is the east longitude of the vehicle
COLA	Cos λ
SNALF	Sin α where α is the right ascension of the vehicle
CSALF	Cos α
FJ	12-cell array containing the values of the desired zonal harmonic constants
C	6 x 6 array used in the simulation of the sectorial and tesseral harmonics (see JCS subroutine)
S	6 x 6 array as above

N1 Degree of the highest zonal harmonic

N2 Degree of the highest sectorial harmonic

N3 Degree of the highest tesseral harmonic

CMU Earth's GM (er^3/min^2)

TR Magnitude of the radius vector, Earth to vehicle (er)

TR3 The cube of TR

2. Calling sequence

—

C. Output

1. COMMON

TPOT Perturbative acceleration of the vehicle in x, y, z, inertial coordinate system due to earth's potential function

2. Calling sequence

—

D. Error/action messages

—

SUBROUTINES USED

A. Library

—

B. Program

—

EQUATIONS

This is a recursive computation, formulated as described in the following paragraphs.

Acceleration in a local rectangular system (f, g, h) with h along the outward geocentric vertical, f directed south and g directed east.

$$a_f = \cos\phi \sum_{n=2}^{N1} \left(J_n r^{-n-2}\right) \rho_n'$$

$$+ \sum_{m=2}^{N2} m r^{-m-2} \sin\phi \left(\sec\phi\ \rho_m^m\right)(C_{mm} \cos m\lambda + S_{mm} \sin m\lambda)$$

$$- \sum_{m=1}^{N3} \sum_{n=m+1}^{N3} r^{-n-2} \left(\cos\phi\, \rho_n^{m'}\right)(C_{nm} \cos m\lambda + S_{nm} \sin m\lambda)$$

$$a_g = - \sum_{m=2}^{N2} m r^{-m-2} \left(\sec\phi\ \rho_m^m\right)(C_{mm} \sin m\lambda - S_{mm} \cos m\lambda)$$

$$- \sum_{m=1}^{N3} m \sum_{n=m+1}^{N3} r^{-n-2} \left(\sec\phi\, \rho_n^m\right)(C_{nm} \sin m\lambda - S_{nm} \cos m\lambda)$$

$$a_h = \sum_{n=2}^{N1} (n+1) \left(J_n r^{-n-2}\right) \rho_n$$

$$- \cos\phi \left[\sum_{m=2}^{N2} (m+1) r^{-m-2} \left(\sec\phi\ \rho_m^m\right)(C_{mm} \cos m + S_{mm} \sin m\lambda) \right.$$

$$\left. + \sum_{m=1}^{N3} \sum_{n=m+1}^{N3} (n+1) r^{-n-2} \left(\sec\phi\, \rho_n^m\right)(C_{nm} \cos m\lambda + S_{nm} \sin m\lambda) \right]$$

where

$$\rho_n = \left[(2n-1) \sin\phi\ \rho_{n-1} - (n-1)\ \rho_{n-2}\right]/n$$

$$\rho_o = 1$$

$$\rho_1 = \sin\phi$$

$$\rho_n' = \sin\phi\ \rho_{n-1}' + n\ \rho_{n-1}$$

$$\rho_1' = 1$$

and

$$\left(\sec\phi\,\rho_m^m\right) = (2m-1)\cos\phi\left(\sec\phi\,\rho_{m-1}^{m-1}\right)$$

$$(\sec\phi\,\rho_1^{1}) = 1$$

$$\sec\phi\,\rho_n^m = \left[(2n-1)\sin\phi\left(\sec\phi\,\rho_{n-1}^m\right) - (n+m-1)\left(\sec\phi\,\rho_{n-2}^m\right)\right]/(n-m)$$

$$\sec\phi\,\rho_{m-1}^m = 0$$

and

$$\left(\cos\phi\,\rho_m^{m'}\right) = -m\sin\phi\left(\sec\phi\,\rho_m^m\right)$$

$$\left(\cos\phi\,\rho_m^{m'}\right) = -n\sin\phi\left(\sec\phi\,\rho_n^m\right) + (n+m)\left(\sec\phi\,\rho_{n-1}^m\right)$$

These accelerations are then rotated to an x, y, z inertial system and scaled by the Earth's GM(μ)

$$\begin{bmatrix} a_x \\ a_y \\ a_z \end{bmatrix} = \mu \begin{bmatrix} \cos\alpha\sin\phi & -\sin\alpha & \cos\alpha\cos\phi \\ \sin\alpha\sin\phi & \cos\alpha & \sin\alpha\cos\phi \\ -\cos\phi & 0 & \sin\phi \end{bmatrix} \begin{bmatrix} a_f \\ a_g \\ a_h \end{bmatrix}$$

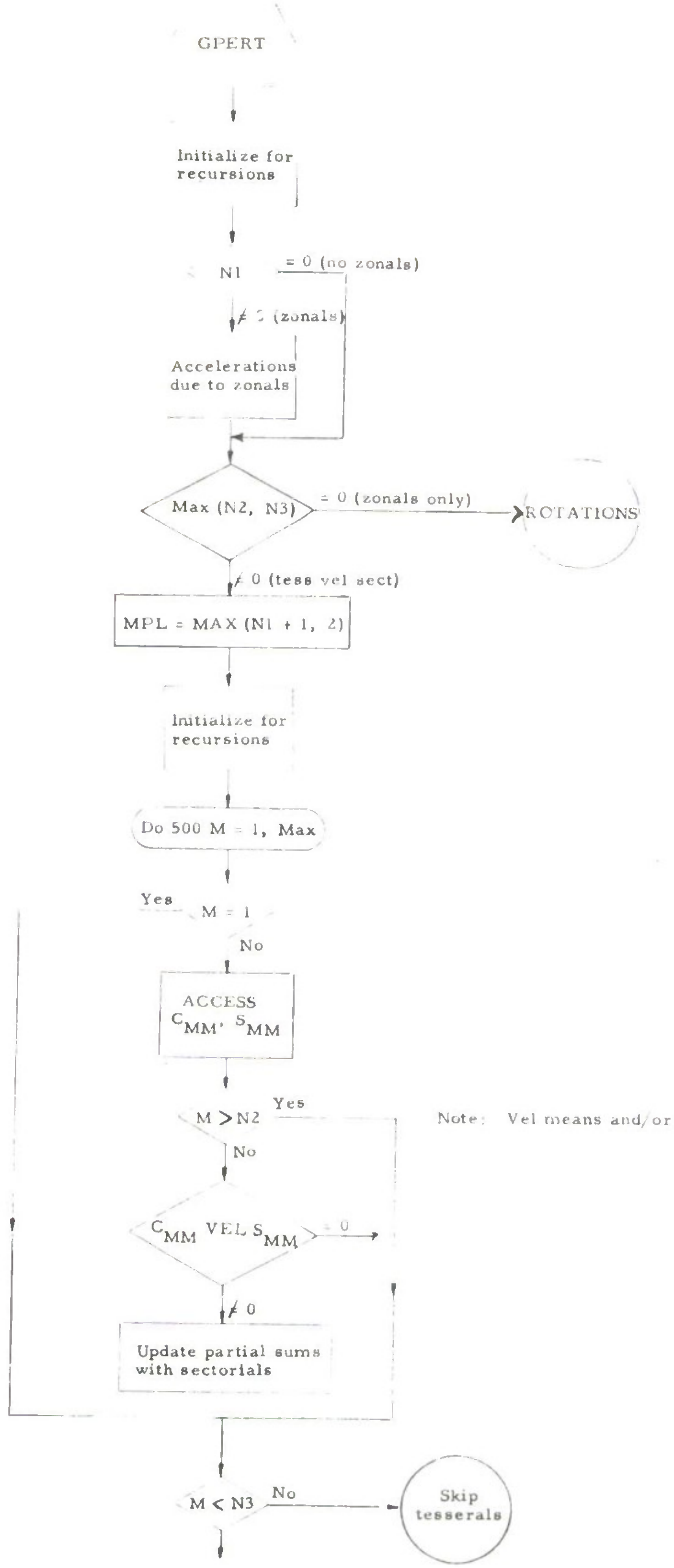


Figure 5-19. GPERT Flow Diagram

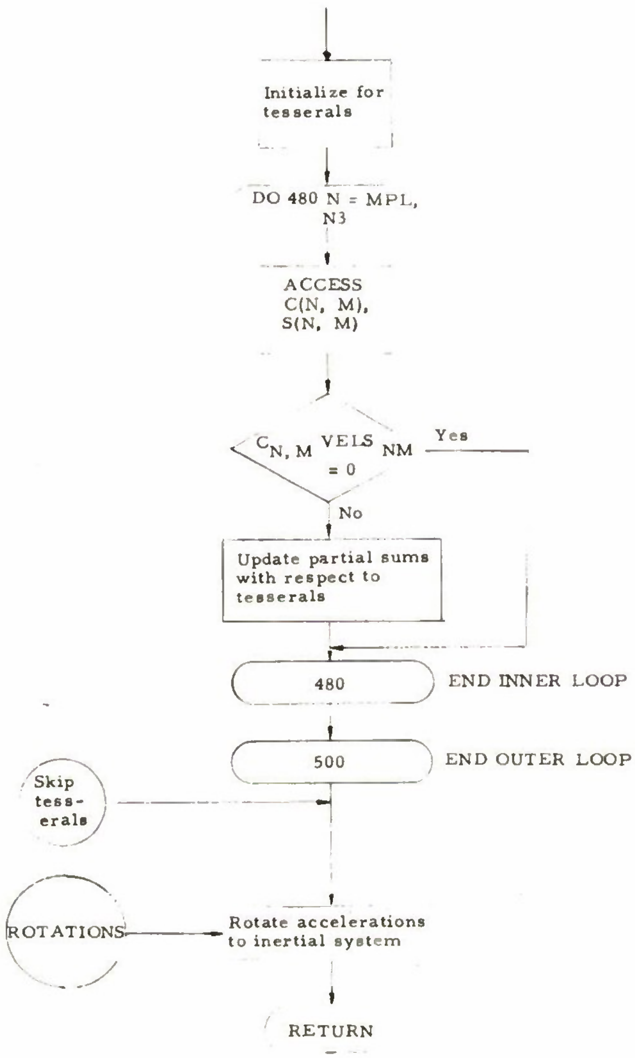


Figure 5-19. GPERT Flow Diagram (Continued)

SUBROUTINE IDENTIFICATION

A. Title

HUMAH

B. Segment

NRTPOD - Input Processor
PREMOD

C. Called by subroutines

PRAUPD
PRTATA
APPLY
SUPMAT
STSMAT

FUNCTION

This subroutine functions in converting a vector, A^TA matrix, or the $(A^TA)^{-1}$ matrix from machine units to human units or from human units to machine units. The A^TA is an upper triangular matrix, and the $(A^TA)^{-1}$ is a lower triangular matrix.

USAGE

A. Calling sequence

CALL HUMAH (A, I, B, J, K, L)

B. Input

1. COMMON

2. Calling sequence

   a) A(I) starting location of the array to be converted

   b) B(J) starting location of the scaling vector

   c) K dimension of A and B

   d) L
      - L = + 1, if a vector is to be converted from machine unit to human units.
      - L = - 1, if a vector is to be converted from human units to machine units.
      - L = + 2, if an A^TA matrix is to be converted from machine units to human units.
      - L = - 2, if an A^TA matrix is to be converted from human units to machine units.

$L = +3$, if an $(A^T A)^{-1}$ matrix is to be converted from machine units to human units.

$L = -3$, if an $(A^T A)^{-1}$ matrix is to be converted from human units to machine units

C. Output

1. COMMON

—

2. Calling sequence

A(I) The matrix or vector A in the changed units defined by L

D. Error/action messages

—

SUBROUTINES USED

A. Library

IABS	Absolute value

B. Program

—

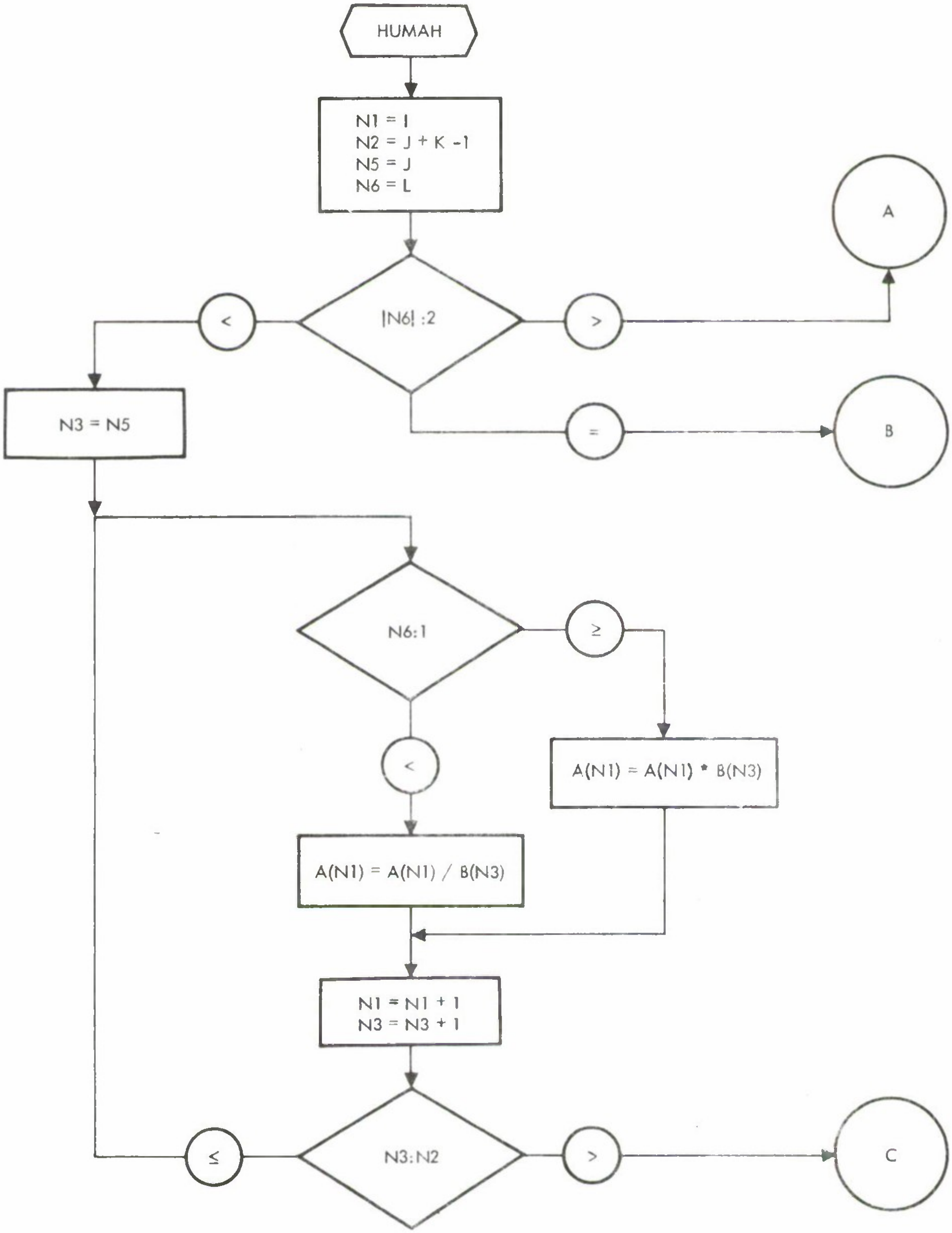


Figure 5-20. HUMAH Flow Diagram

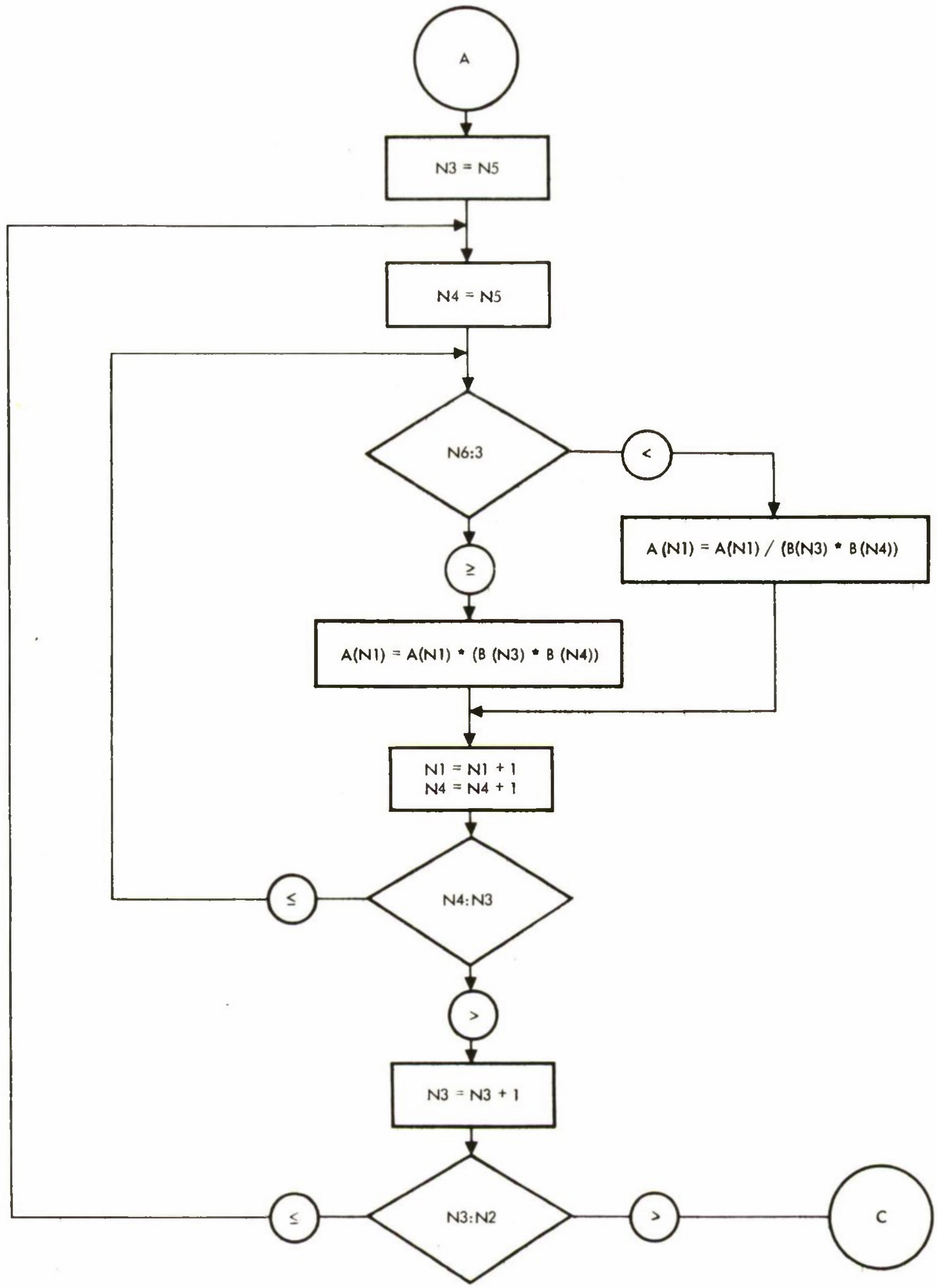


Figure 5-20. HUMAH Flow Diagram (Continued)

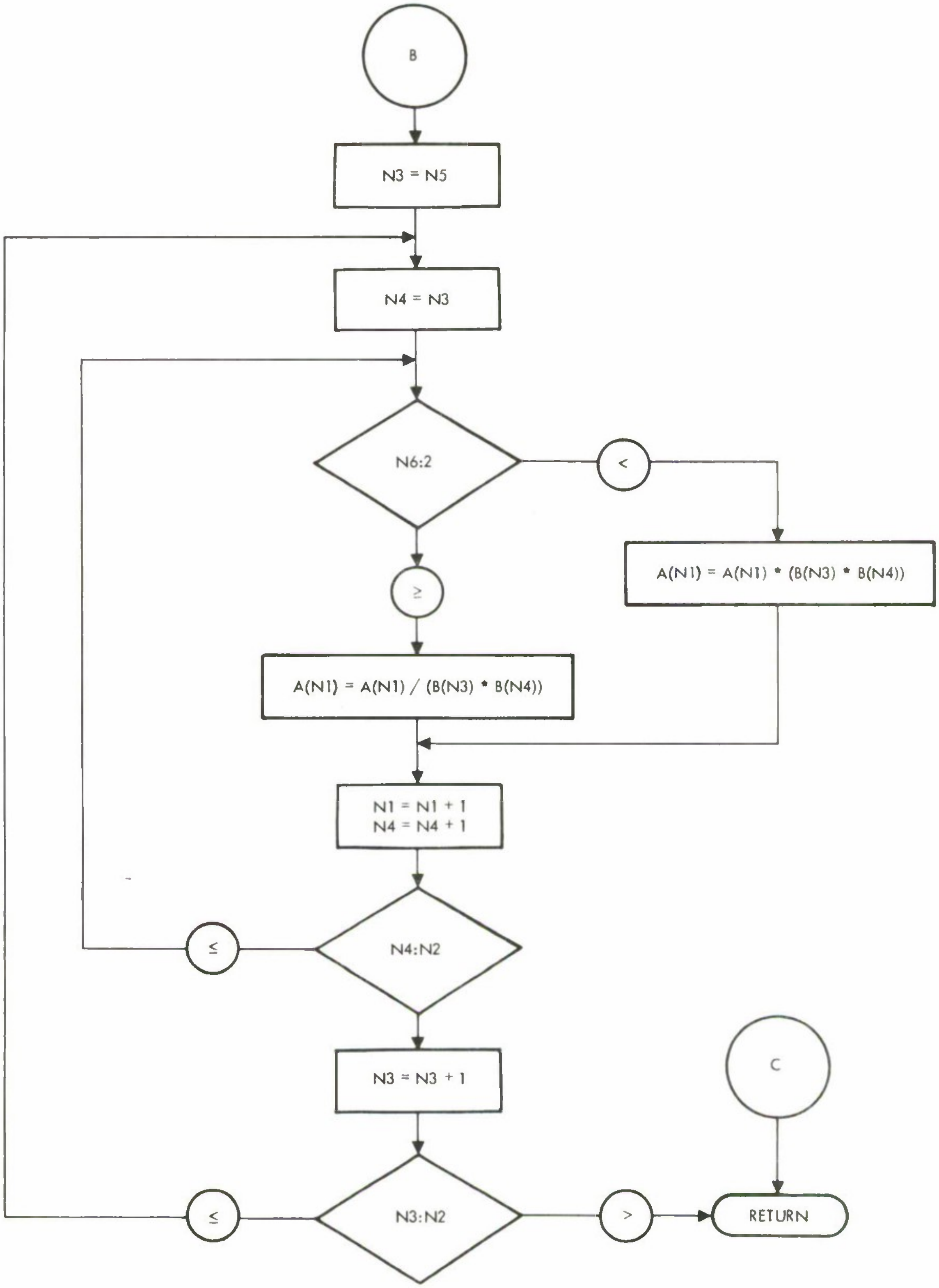


Figure 5-20. HUMAH Flow Diagram (Continued)

SUBROUTINE IDENTIFICATION

A. Title

INPUT

B. Segment

NRTPOD - Input processor

C. Called by subroutines

NRTPOD (DRIVER)

FUNCTION

INPUT's function is to serve as a main driver for the Input Processor Link. It utilizes routines to initialize COMMON storage, process NAMELIST input, assign variable storage, and process sensor information and observations.

USAGE

A. Calling sequence

CALL INPUT

B. Input

1. //COMMON

-

2. Calling sequence

-

C. Output

1. //COMMON

-

2. Calling sequence

-

D. Error/action messages

-

E. Internal storage

1. //COMMON

NDAYS	Number of days of ephemeris data (positions of the moon and sun) accepted on input
DVEHN	Array of 3 BCD words identifying the vehicle number and name (Input to columns 4-17 on JDC card)
DHEAD	2 BCD words containing arbitrary header information. (Input to columns 18-29 on JDC card)
PREFLG	NRTPOD control flags (columns 31-40 on JDC card)
DCFLG	NRTPOD control flags (columns 41-50 on JDC card)
PSTFLG	NRTPOD control flags (columns 51-60 on JDC card)
KIN	Symbolic input tape number
KOUT	Symbolic output tape number
COMLST	Contains size of variable storage

2. Labeled COMMON

/VSTR/	
VSTR	Variable storage array
/INPP/	
DTMP	Temporary cells containing sensor information used by the Input Processor Link
DATA	Temporary cells used only by the Input Processor Link
/EPHCOM/	
ECOM	Array of storage containing the moon and sun ephemeris of positions (Input to NRTPOD)

SUBROUTINES USED

A. Library -

-

B. Program

SETCON	Sets up program constants.
RDDATA	Routine to read NAMELIST input and Ephemeris data.
ASSIGN	Establishes storage assignments for VSTR (variable storage) arrays.

SETTAB	Sets up VSTR (NIDP), VSTR (NPRCD), VSTR (NPBIS), VSTR (NSCALE), VSTR (NBDNS), and DTMP tables.
SDELET	Moves observation deletion numbers from DATA storage to VSTR (NIDLED).
STSMAT	Convert the upper triangular S matrix in DATA storage from human units to machine units and then transfer to VSTR (NATA).
SUPMAT	Move the initial update matrix from DATA storage to VSTR (NR) and convert from human units to machine units.
DPRLM	Sets up preliminary information for the input processor. This information concerns epoch time and mode of epoch position and velocity.
PRECES	Precess ephemeric data from mean equator and equinox of 1950.0 to the equator and true equinox of date.
DPROS	Issue calls on the sensor and observation loading routines if required.
PRCONS	Prints program constants, input data, variable storage pointers, and working storage cells.

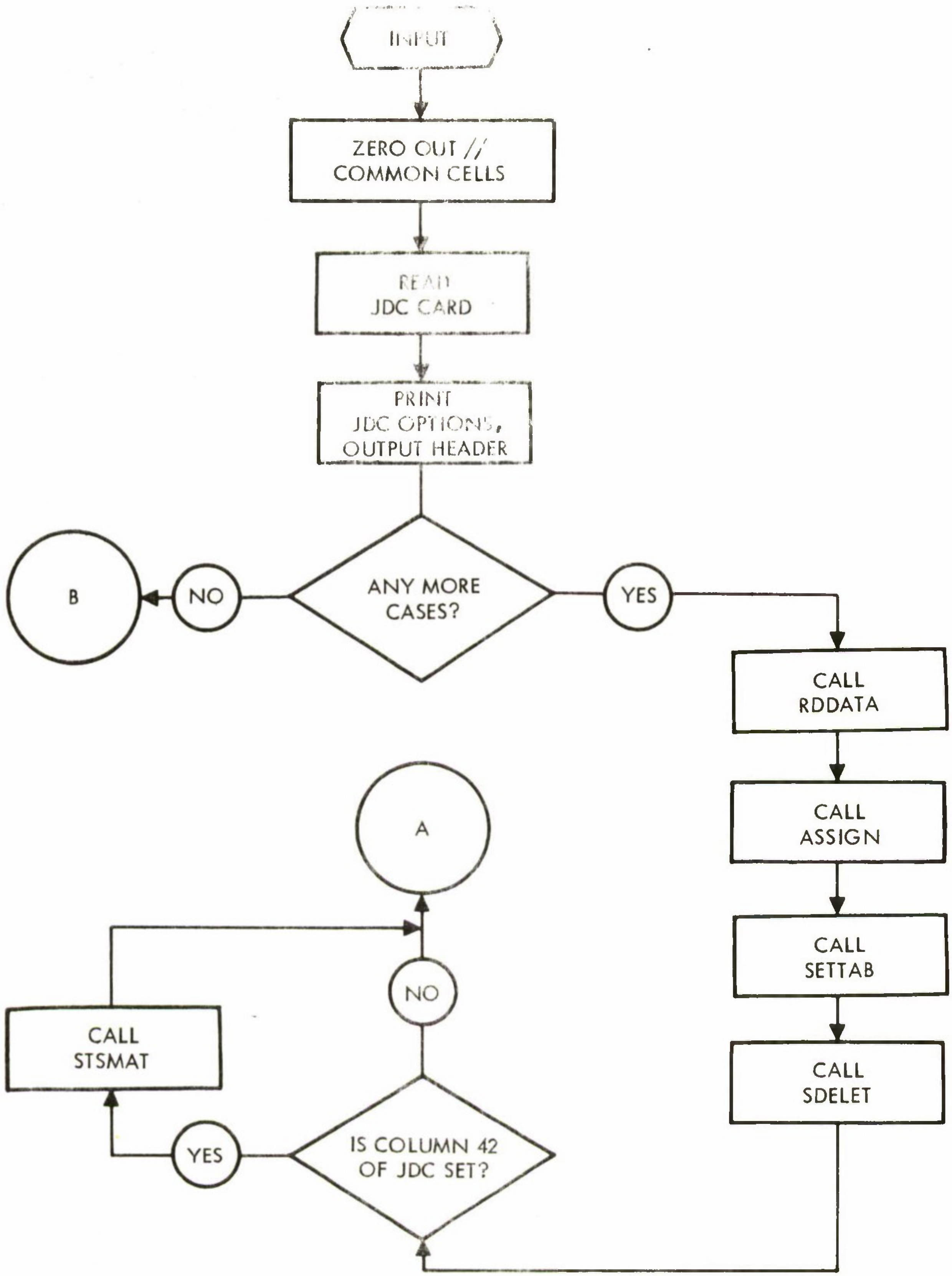


Figure 5-21. INPUT Flow Diagram

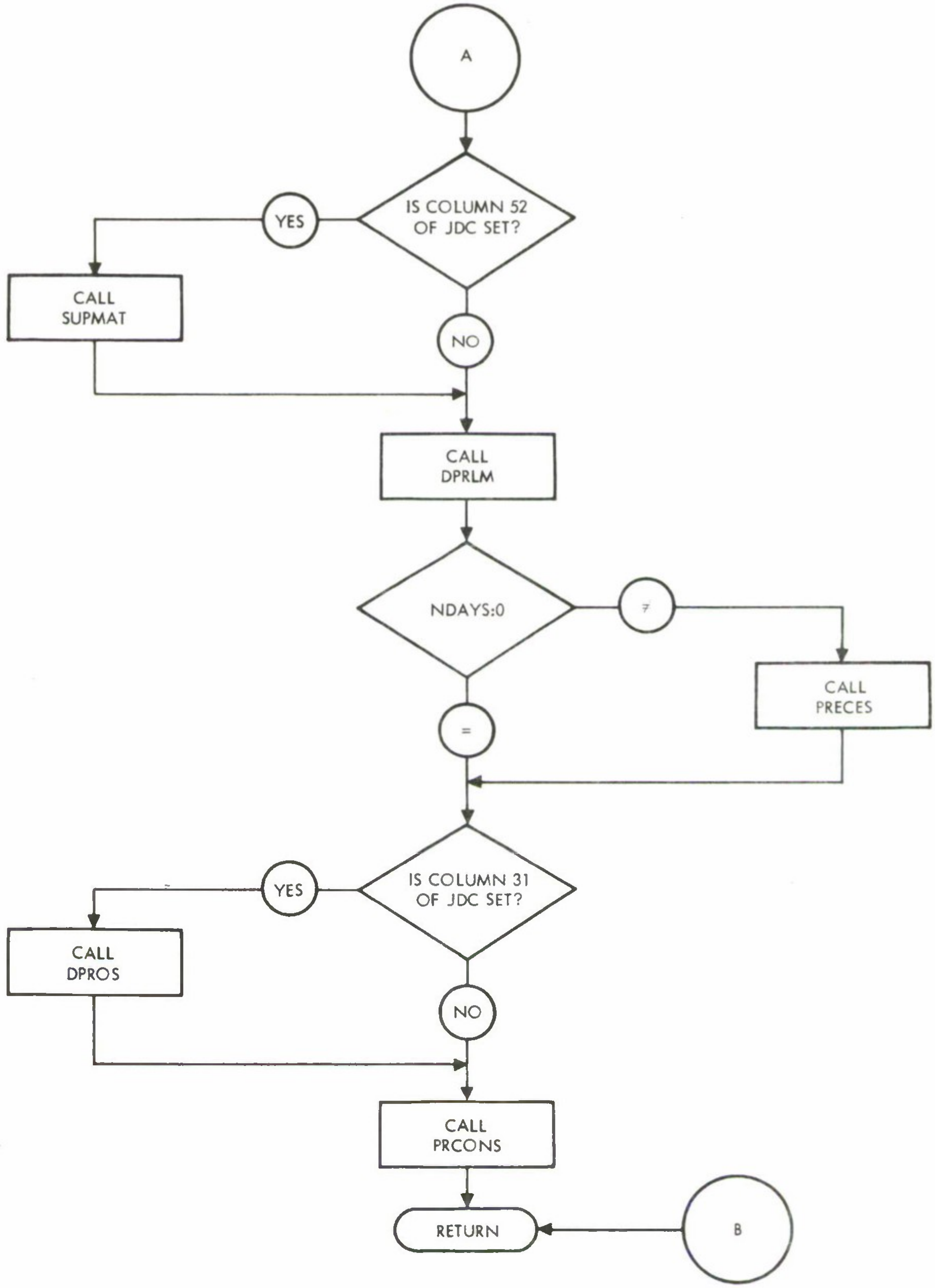


Figure 5-21. INPUT Flow Diagram (Continued)

SUBROUTINE IDENTIFICATION

A. Title

IPRNT

B. Segment

PREMOD

C. Called by subroutines

DPRLM

PREMOD

FUNCTION

To output:

a) A time header of year, month, day, hour, minutes, and seconds

b) The right ascension of Greenwich at 0 hours of the given day

c) The value of (x, y, z, $\dot{x}$, $\dot{y}$, $\dot{z}$) and (α, δ, β, A, R, V) at the given time

This routine is entered after the preliminary epoch has been established (from DPRLM) and after the final epoch has been determined (from PREMOD).

USAGE

A. Calling sequence

CALL IPRNT

B. Input

1. COMMON

KOUT	Number of the output device
TALFAG	Right ascension of the Greenwich meridian at 0 hours of the day of interest (radians)
CDEG	Degrees per radian
DYEAR	First location of 5-cell array containing integer year-1900, month, day, hour, and minute of epoch
DSEC	Seconds
TNOMX	A 6-cell vector containing x, y, z, $\dot{x}$, $\dot{y}$, and $\dot{z}$ in kilometers and seconds

2. Calling sequence

-

C. Output

1. COMMON

-

2. Calling sequence

-

D. Error/action messages

-

E. Internal storage

TEMP, ITEMP	Temporary storage

SUBROUTINES USED

A. Library

.FCNV.	.FVIO.
.FFIL.	.FWRD.

B. Program

CTOP	Convert Cartesian elements to polar

EQUATIONS

SUBROUTINE IDENTIFICATION

A. Title

IPRNT

B. Segment

NRTPOD - Input Processor

C. Called by subroutines

DPRLM

FUNCTION

The function is to print out the header, initial conditions, vehicle number and name, and drag and radiation pressure parameters, if any.

USAGE

A. Calling sequence

CALL IPRNT

B. Input

1. COMMON

a. Labeled COMMON

/INPP/

DRAGCD	Coefficient of Drag (C_D)
RPGAM	Radiation pressure parameter, γ, reflectivity constant.

b. Blank COMMON

CKMFT	Conversion constant from ft to km
CMTER	Conversion constant from earth radii to meters
CDEG	Conversion constant from radians to degrees
KOUT	Symbolic output tape number (print)
DVEHN	Vehicle no. and name specified on input (JDC card columns 4-17)
CDAD2M	Ballistic drag parameter, CdA/2M (Internal units $ft^2/slug$)
SGAMAM	Radiation pressure parameter, $S\gamma A/M$ (Internal units $\frac{e.r.^3}{min^2}$
TALFAG	α_g for midnight, day of epoch
DYEAR	Epoch year
DMNTH	Epoch month
DDAY	Epoch day

DHOUR	Epoch hour
DMIN	Epoch minutes
DSEC	Epoch seconds
TNOMX	Initial Cartesian coordinates (x, y, z, $\dot{x}$, $\dot{y}$, $\dot{z}$)
TNOMP	Initial polar coordinates (α, δ, β, A, R, V)

2. Calling sequence

-

C. Output

1. COMMON

-

2. Calling sequence

-

D. Error/action messages

-

E. Internal storage

1. COMMON

-

2. Temporary storage

S - radiation pressure constant $\left(\frac{\text{Kilogram-meters}}{\text{sec}^2}\right)$

CKGSG - conversion constant from slugs to kilograms.

SUBROUTINES USED

A. Library

-

B. Program

-

SUBROUTINE IDENTIFICATION

A. Title

JACHIA

B. Segment

MHESPOD
PREMOD
NRTPOD

C. Called by subroutine

DRAG

FUNCTION

Computes the density of air using the Lockheed Jacchia atmospheric model.

USAGE

A. Calling sequence

CALL JACHIA

B. Input

1. COMMON

TALT	Altitude of vehicle (ft)
CFTNM	Conversion from nautical miles to feet
TLIST	Numerical integration working storage (JACHIA uses position and velocity vectors of the vehicles)
TJDATE	Julian date of midnight, epoch day
C2PI	2π
TR	Radius magnitude of vehicle (e.r.)
TG	Time to integrate to (min)
TEMP	Temporary working storage

2. Calling sequence

—

C. Output

1. COMMON

TRHOA	Density of air (slugs/ft^3)

SUBROUTINE IDENTIFICATION

A. Title

JACHIA

B. Segment

MHESPOD

PREMOD

NRTPOD

C. Called by subroutines

DRAG

FUNCTION

Computes the density of air using the Lockheed Jacchia atmospheric model.

USAGE

A. Calling sequence

CALL JACHIA

B. Input

1. COMMON

TALT	Altitude of vehicle (ft)
CFTNM	Conversion from nautical miles to feet
TLIST	Numerical integration working storage (JACHIA uses position and velocity vectors of the vehicles)
TJDATE	Julian date of midnight, epoch day
C2PI	2π
TR	Radius magnitude of vehicle (e. r.)
TG	Time to integrate to (min)
TEMP	Temporary working storage (min)

2. Calling sequence

—

C. Output

1. COMMON

TRHOA - Density of air slugs/ft^3

2. Calling sequence

—

D. Error/action messages

—

SUBROUTINES USED

A. Library

COS

SIN

EXP

B. Program

ATM59

EQUATIONS

In the following expressions, the various parameters and geocentric equatorial coordinates are defined, thus:

$X, Y, Z =$ Geocentric Cartesian coordinates of the field point, where X and Y are in the earth's equatorial plane (X positive, in the direction of the vernal equinox of date; Y positive outward on an axis 90° east) and Z is measured north along the earth's spin axis.

$R =$ Geocentric distance of the field point $= \sqrt{X^2 + Y^2 + Z^2}$

$\ell, m, n =$ Direction cosines of field point: $\ell = \frac{X}{R},\ m = \frac{Y}{R},\ n = \frac{Z}{R}$

$d =$ Days elapsed since Dec. 31, 1957

$\lambda_s =$ Celestial longitude of sun; an adequate approximation in radians is:

$$\lambda_s = 0.017203d + 0.0335 \sin 0.017203d - 1.410$$

$\epsilon =$ Inclination of ecliptic = .4092 rad

$\ell_s, m_s, n_s =$ Direction cosines of sun

$$\ell_s = \cos \lambda_s$$

$$m_s = \sin \lambda_s \cos \epsilon$$

$$n_s = \sin \lambda_s \sin \epsilon$$

EQUATIONS (Continued)

$\psi =$ Geocentric angle between sun and field point, $\cos\psi = \ell\ell_s + mm_s + nn_s$

$\theta =$ longitudinal lag of diurnal bulge; an adequate average is .55 rad

$\psi' =$ Geocentric angle between diurnal bulge and field point; $\cos\psi' = (\ell\ell_s + mm_s)\cos\theta + m\ell_s - \ell m_s)\sin\theta + nn_s$

$h =$ Altitude above ellipsoidal earth in nautical miles

$F_{10.7} =$ Flux of 10.7 cm solar radiation in units of 10^{-20} watt/meter^2; an adequate approximation if $F_{10.7} = 1.5 + 0.8\cos(2\pi d/4020)$

$\rho =$ Atmospheric density in slug/ft^3

0 to 76 n mi. In this region, the ARDC (1959) atmosphere is to be used with a correction factor in the form:

$$p = p_{1959\ \mathrm{ARDC}}\left\{1 - 0.6n^3\left[1 - \cos 2\pi\left(\frac{h-16}{34}\right)\right]\cos 2\pi\left(\frac{d+9}{365}\right)\right\}$$

applied between 16 and 50 nm.

76 to 108 n mi. The following formula will serve as a connection between the two bordering regions. The slope of the profile will often be discontinuous at the end points:

$$\rho = 5.606 \times 10^{-12} \times \left(\frac{76}{h}\right)^{7.18}\left[\frac{108-h}{32} + 0.85\left(\frac{h-76}{32}\right)^{4/3} F_{10.7}\right]$$

$$\times\left[1 + \frac{h-76}{153}\ \frac{1+\cos\psi'}{2}^{3}\right]$$

108 to 378 n mi. Jacchia's formula (13) can be written, using the 10.7 cm flux, as

$$\rho = \rho_o(h)\left(0.85\,F_{10.7}\right)\left\{1 + 0.19\left[\exp(0.0102\,h) - 1.9\right]\left(\frac{1+\cos\psi'}{2}\right)^3\right\}$$

EQUATIONS (Continued)

$$\log_{10} \rho_o(h) = -15.738 - 0.00368\, h + 6.363 \exp(-0.0048\, h)$$

378 to 1000 nm. For these altitudes only an approximate form can be given:

$$\rho = 0.00504 \frac{F_{10.7}}{h^5} \left[\left(\frac{1 + \cos \psi'}{2} \right)^3 \left(1 - \frac{6 \times 10^6}{h^3} \right) + \frac{6 \times 10^6}{h^3} \right]$$

SUBROUTINE IDENTIFICATION

A. Title

JCBINV

B. Segment

PREMOD

C. Called by subroutine

UPDATE

FUNCTION

To calculate the inverse of the variational equations matrix using the Jacobi inverse technique.

USAGE

A. Calling sequence

CALL JCBINV (A, B)

B. Input

1. COMMON

-

2. Calling sequence

A. . . Matrix to be inverted (assumed stored as a two-dimensional 6 x 6 array)

C. Output

1. COMMON

-

2. Calling sequence

B. . . Inverse of A (assumed stored as a two-dimensional 6 x 6 array)

D. Error/action messages

-

SUBROUTINES USED

A. Library

-

B. Program

-

EQUATIONS

Consider the variational equations

$\ddot{p} = a(t)\, p$ where p is a 3 x 1 column vector and a(t) a 3 x 3 symmetric matrix

this is equivalent to

$$\dot{P} = A(t)\, P \quad \text{where} \quad P = \begin{bmatrix} P \\ \dot{P} \end{bmatrix} \quad \text{and} \quad A = \begin{bmatrix} 0 & I \\ a & 0 \end{bmatrix}$$

If we let

$$J = \begin{bmatrix} 0 & I \\ -I & 0 \end{bmatrix}$$ we note JA is symmetric.

Let M(t) be a 6 x 6 matrix satisfying

$$\dot{M} = AM \;\epsilon\; M(t_o) = I$$

Since JA is symmetric so is the product

$$M' \, JAM = M' \, J\dot{M}$$

and it follows that

$$M' \, J\dot{M} = (M' \, J\dot{M})' = \dot{M}' J' M = -\dot{M}' \, JM$$

And as a consequence, we find

$$\frac{d}{dt} (M' JM) = M' J\dot{M} + \dot{M}' JM = 0$$

and conclude that M' JM is a constant

$$M' (t) JM (t) = M' (t_o) JM (t_o) = J$$

Since J is orthogonal

$$M^{-1} = J' M'J$$

Partitioning M into 3 x 3 submatrices:

$$M = \begin{bmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{bmatrix}$$

$$M^{-1} = \begin{bmatrix} M'_{22} & -M'_{12} \\ -M'_{21} & M'_{11} \end{bmatrix}$$

SUBROUTINE IDENTIFICATION

A. Title

JCS

B. Segment

PREMOD
NRTPOD

C. Called by subroutine

SETSTR

FUNCTION

To determine the geopotential model to be used in the trajectory simulation. This routine sets up 3 working arrays (FJ, C, S) for subroutine GPERT from the master constant arrays CJ, CJNM, CLAMNN.

USAGE

A. Calling sequence

CALL JCS

B. Input

1. COMMON

ZONAL	12 flags to indicate which zonal harmonics to be included in the earths potential model. If the i'th entry is zero do not include, if non-zero include J_i.
CJ	The value of $J_1, J_2, \ldots, J_{12}$ for the earth.
CLAMNN	The value of $\lambda_{11}, \lambda_{22}, \ldots, \lambda_{66}$ for the earth. These are the sectorial phase angles, in degrees.

CJNM

$$\begin{bmatrix} J_{11} & \lambda_{21} & \lambda_{31} & & & \lambda_{61} \\ J_{21} & J_{22} & \lambda_{32} & & & \lambda_{62} \\ J_{31} & J_{32} & J_{33} & & & \\ & & & J44 & & \\ & & & & J_{55} & \lambda_{65} \\ J_{61} & J_{62} & & & J_{65} & J_{66} \end{bmatrix}$$

A two-dimensional array with the λ_{ij} in degrees.

SECT	6 flags to indicate which sectorial harmonics are to be included in the earth's potential model. If the i'th entry is zero do not include, if non-zero include J_{ii}, λ_{ii}.
TESS	A 15-cell vector of code words to describe the tesseral harmonics to be included in the earth's potential mode. Each code word is of the form 10 M + N. The program will include the tesseral harmonics due to J_{MN}, λ_{MN} in the model. M must be greater than N, and the list is assumed terminated whenever a 0 entry is encountered.
CDEG	Degrees per radian.
KOUT	Logical number of the output device.

2. Calling sequence

-

C. Output

1. COMMON

N1	The degree of the highest zonal harmonic requested (N1 ≤ 12).
N2	The degree of the highest sectoral harmonic requested (N2 ≤ 6).
N3	The degree of the highest tesseral harmonic requested (N3 ≤ 6).
FJ	A 12-cell vector containing the values of the zonal harmonics to be included in the geopotential model.

If a cell is 0, it indicates that the corresponding harmonic is not to be simulated.

C, S — Two-dimensional arrays containing expressions in J_{ij}, λ_{ij} (see equations). Only the lower triangular portion of each array is used. If a cell is zero, the J_{ij}, λ_{ij} are not simulated in GPERT.

2. Calling sequence

-

D. Error-action messages

If the degree (M) of a requested tesseral harmonic is greater than the order (N) as decoded from the TESS input array, the following error comment is printed:

****ILLEGAL TESSERAL JXX REQUESTED, IGNORING AND PROCEEDING

SUBROUTINES USED

A. Library

.COS.	.FCNV.	.FVIO.
.SIN.	.FFIL.	.FWRD.

B. Program

-

EQUATIONS

The following equations are used to convert the tesseral and sectorial J_{ij}, λ_{ij} to their corresponding trigonometric form:

$$\left.\begin{aligned} C_{ij} &= J_{ij} \cos (j\lambda_{ij}) \\ S_{ij} &= J_{ij} \sin (j\lambda_{ij}) \end{aligned}\right\} \quad i, j = 1, 6$$

SUBROUTINE IDENTIFICATION

A. Title

JTOC

B. Segment

PREMOD

C. Called by Subroutine

MTOC	Updates a set of mean orbital elements and transforms them to osculating orbital elements and then to Cartesian elements

FUNCTION

This routine converts a Julian date given in integral and fractional days to a calendar date expressed in year, month, day, hours, minutes, seconds. The given Julian day is modulated by 2,400,000.5 which conforms to the SPADATS/SPACETRACK mean element set (card) format specifications.

USAGE

A. Calling Sequence

Call JTOC (DAYINT, DAYFRC, DYEAR, DMNTH, DDAY, DHOUR, DMIN, DSEC)

B. Input

1. COMMON

—

2. Calling Sequence

DAYINT	Integral Julian day
DAYFRC	Fractional Julian day

Note: Both DAYINT and DAYFRC combine to form a complete Julian day mod 2,400,000.5.

For example,

give a Julian date: 2,438,795.02777070,

mod 2,400,000.5

results in a modulated Julian day:

38794.52777070

In this case DAYINT = 38794.
DAYFRC = .52777070

C. Output

1. COMMON

—

2. Calling Sequence

DYEAR	year
DMNTH	month
DDAY	day
DHOUR	hours
DMIN	minutes
DSEC	seconds

D. Error/Action messages

—

SUBROUTINES USED

A. Library

AINT

B. Program

CDCD modulates a given calendar date

SUBROUTINE IDENTIFICATION

A. Title

LEGS1

B. Segment

MHESPOD
NRTPOD

C. Called by subroutine

RADR

FUNCTION

This subroutine transforms the augmented matrix (A, B) of the system Ax = B into the augmented normal matrix.

$$\begin{bmatrix} A^T A & A^T B \\ B^T A & B^T B \end{bmatrix}$$

Since the augmented normal matrix is symmetric, only the upper triangle part is stored.

USAGE

A. Calling sequence

Call LEGS1 (K, I3, SUS)

B. Input

1. COMMON

NAROW	Identifies the starting location where 1 row of the augmented matrix (A, B) is stored
NATA	Identifies the starting location of where the triangular $A^T A$ is stored
NBDNS	Identifies the starting location for the bounds, used by LEGS2
NPR	Number of all parameters to solve for

2. Calling sequence

   K Row number of A

   I3 I3 is used only when K = 1. If $I3 \geq 0$, the $A^T A$ section is cleared before computing $A^T A$. If $I3 < 0$, the section is not cleared.

C. Output

1. COMMON

   VSTR (NATA) Where the triangular $A^T A$ is stored

2. Calling sequence

   SUS Current sum of squares of weighted residuals

D. Error/action messages

—

SUBROUTINES USED

A. Library

—

B. Program

—

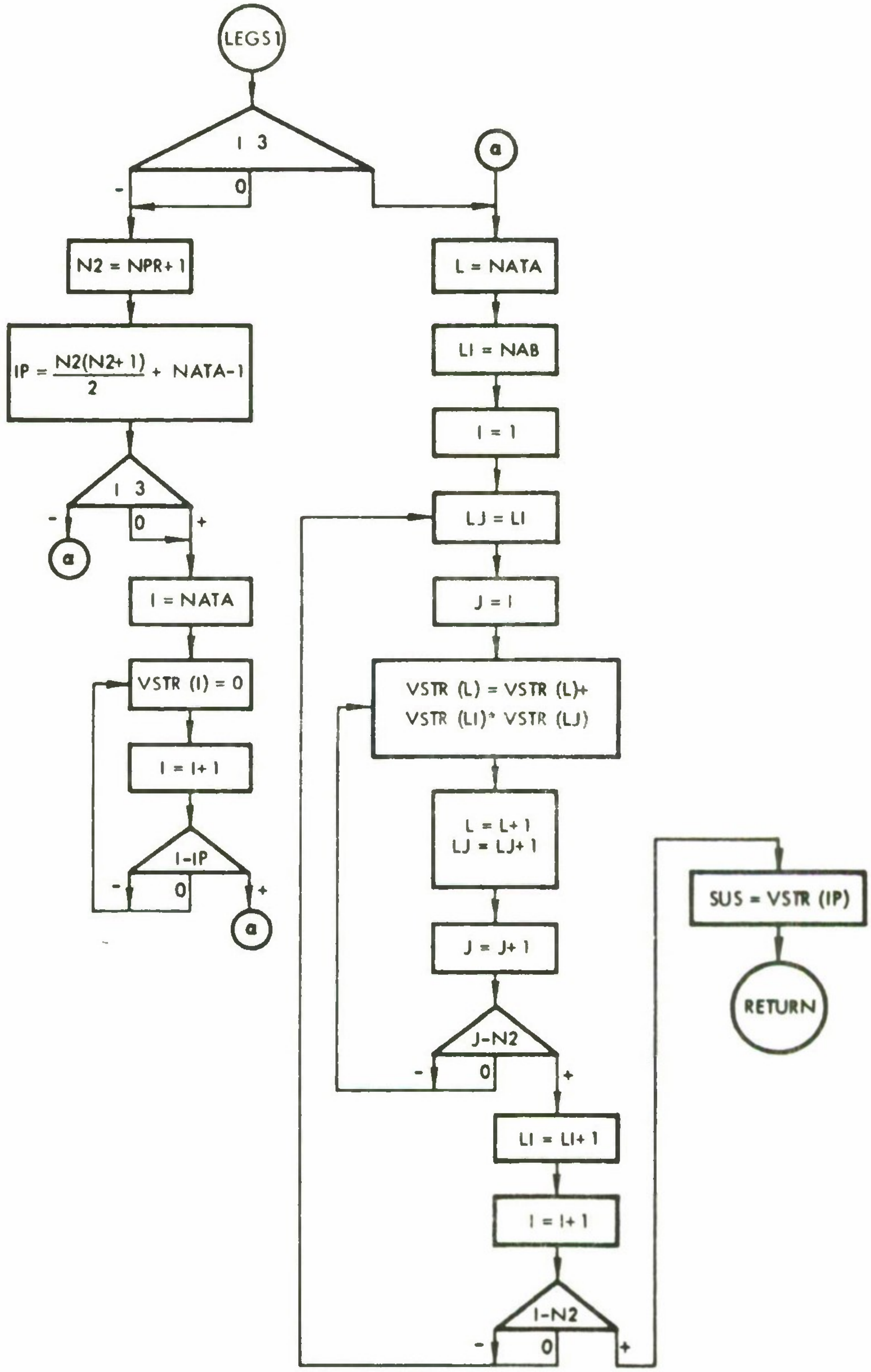


Figure 5-22. LEGS1 Flow Diagram

SUBROUTINE IDENTIFICATION

A. Title

LEGS2

B. Segment

MESPOD
NRTPOD

C. Called by subroutine

FIT
PRAUPD (In NRTPOD version only)

FUNCTIONS

a) To solve an overdetermined linear system of equations $Ax = b$

b) To compute the inverse of $A^T A$

c) After solving for x, to compute $||Ax - b||^2$

USAGE

A. Calling sequence

Call LEGS2 (NDPAR, Z, SUSP, I1, I2, I4)

B. Input

1. COMMON

NATA	Identifies the starting location of where the upper triangular $A^T A$ is stored
NBDNS	Identifies the starting location for the bounds used by LEGS2
NPR	Number of all parameters to solve for
NR	Identifies the starting location of where the inverse $A^T A$ (in triangular form) is stored

2. Calling Sequence

NDPAR	The index for variable storage where the solution vector x is to be stored
I1 I2 I4	Option control flags

C. Output

1. COMMON

VSTR (NDPAR)	Start of the array containing the solution vector x
VSTR (NR)	Start of an array containing $(A^TA)^{-1}$ as a lower triangular matrix

2. Calling sequence

Z	Flag to indicate if the solution was affected by the bounds. If the flag is non-zero the solution was affected by the bounds
B	Predicted SOS for the next iteration

SUBROUTINES USED

A. Library

—

B. Programs

—

EQUATIONS

To solve for differential corrections, find x so that $\|Ax - b\|^2$ is minimum under the side condition that

$$\sum_i \left(\frac{x_i}{B_i}\right)^2 \leq 1 \qquad B_1, B_2, \cdots, = \text{bounds}$$

The side condition may be described as

$$\begin{bmatrix} B_1^{-2} & 0 \; . \; . \; . \; . & \\ & & \\ 0 & B_2^{-2} & \\ . & & . \\ . & & \quad . \\ & & \qquad . \end{bmatrix} = B^{-2}$$

B^{-2} is a diagonal matrix

where

$$x^T B^{-2} x \leq 1$$

Bounds

Define x(z) as the solution of the linear system

$$(A^TA + zB^{-2})\,X = A^Tb$$

where B^{-1} is the diagonal matrix with the (i, i) diagonal element being B_i^{-1} if $B_i > 0$ and $B_i < 0$. If $B_i = 0$, the i^{th} row and column of the augmented normal matrix is ignored and x_i is set to zero.

a) The routine finds x = x(0). If $(B^{-2}\,x,\ x) \leq 1 + \epsilon_1$ the solution is obtained. Otherwise

b) Define $y(z) = \left[B^{-2}\,x(z),\ x(z)\right]$. Now $y(0) > 1 + \epsilon_1$. Compare y(h), y(1 0h), y(100h), . . . , until a value of z is found with $1 - \epsilon_2 \leq y(z) \leq 1 + \epsilon_1$, in which case x(z) is the solution or until two values of z are found with $y(z_1) > 1 + \epsilon_1$ and $y(z_2) < 1 - \epsilon_2$. The required value of z is now bracketed. Then

c) Choose a value z_3 between z_1 and z_2. If $1 - \epsilon_2 \leq y(z_3) \leq 1 + \epsilon_2$, then $y(z_3)$ is the solution. Otherwise

d) Use inverse quadratic interpolation (to zero) to obtain a new guess z_4. If $1 - \epsilon_2 \leq y(z_4) \leq 1 + \epsilon_1$, then $x\,(z_4)$ is the solution. Otherwise

e) Select from the set z_1, z_2, z_3, z_4 the two values of z which bracket the solution most tightly. Use these values as z_1 and z_2 and go back to 3.

The iterative process will stop if the number of solutions of the linear system reaches 20.

Linear System

Let $C = A^TA + zB^{-2}$. The routine finds a matrix S with $SCS^T = D$. S is lower triangular with (-1) on the diagonal. It is easy to find S and D for a l x l matrix C. Assume S and D have been found for a k x k matrix C. Now augment C by another row and column

$$\begin{pmatrix} C & d \\ d^T & a \end{pmatrix}$$

A vector ω and a scalar β are now desired such that

$$\begin{pmatrix} S & 0 \\ \omega^T & -1 \end{pmatrix} \begin{pmatrix} C & d \\ d^T & \alpha \end{pmatrix} \begin{pmatrix} S^T & \omega \\ 0 & -1 \end{pmatrix} = \begin{pmatrix} D & 0 \\ 0 & \beta \end{pmatrix}$$

The requirements are satisfied by

$$\omega = S^T D^{-1} Sd$$

$$\beta = \alpha - \omega^T d$$

The routine builds the matrix S by the above process with k = 2, 3, $\cdots$, N. The final result is a decomposition of the augmented matrix

$$\begin{pmatrix} S & 0 \\ \omega^T & -1 \end{pmatrix} \begin{pmatrix} A^T A + zB^{-2} & A^T b \\ b^T A & b^T b \end{pmatrix} \begin{pmatrix} S^T & \omega \\ 0 & -1 \end{pmatrix} = \begin{pmatrix} D & 0 \\ 0 & \alpha \end{pmatrix}$$

and the N-dimensional vector ω which appears above is the solution vector.

Predicted RMS for Next Iteration

Given $b^T b$, $A^T A$, $A^T b$, X, n = total number of observations

$$\text{Predicted RMS} = \frac{1}{\sqrt{n}} \sqrt{b^T b - 2\, x^T (A^T b) + x^T (A^T Ax)}$$

SUBROUTINE IDENTIFICATION

A. Title

LINES

B. Segment

NRTPOD - partials - least square

C. Called by subroutines

1. DCITER
2. RADR
3. PUPB

FUNCTION

LINES accumulates the number of output lines during the printing of residuals. If the line count exceeds 39 a page heading is printed and the count is re-set to 5.

USAGE

A. Calling sequence

CALL LINES (A, NHD)

B. Input

1. COMMON

   KOUT - peripheral output tape number

2. Calling sequence

   a) A - line counter

   b) NHD - head option (not used)

C. Output

a) A - adjusted line counter

SUBROUTES USED

A. Library

.FFIL.

.FVIO.

.FWRD.

B. Program

\-

SUBROUTINE IDENTIFICATION

A. Title

LODOBS

B. Segment

PREMOD

C. Called by subroutine

PREMOD

FUNCTION

This is the main control for the observation card processor. Observation cards are read, biases are applied, the BCT is written, and the observational data is printed on unit KOUT.

USAGE

A. Calling sequence

Call LODOBS

B. Input

1. COMMON

KOUT	Logical number of the output device
NSTAT	Location in VSTR of the master sensor table
TJDATE	The Julian Date at 0 hours day of epoch
CKMER	Kilometers per earth radius
CDEG	Degrees per radian
KBCT	Logical number of the BCT

BIAS — A 60-cell array composed of the following items taken from the station location cards:

BIAS (I) = Station ID (left adjusted .... BCD)
(I+1) = Range bias (km)
(I+2) = Azimuth bias (deg)

(I+3) = Elevation bias (deg)
(I+4) = Range rate bias (km/sec)
(I+5) = Not used
(I+6) = Range σ (km)
(I+7) = Azimuth σ (deg)
(I+8) = Elevation σ (deg)
(I+9) = Range rate σ (km/sec)

Up to 0 stations may appear in BIAS.

2. Calling sequence

—

C. Output

No output through COMMON or the calling sequence, this subroutine writes the observation records on the BCT binary tape.

D. Error/action messages

If the observation type (column 26 of the observation cards) is not 0 or blank, the following message is printed:

**** ILLEGAL OBSERVATION TYPE XX IGNORED

If station ID on the observation card does not match an ID in the BIAS table, the following message is printed:

**** STATION XX NOT IN MASTER SENSOR TABLE

E. Internal storage

BUFF — A 50-cell block to hold 1 observation record on the BCT. The format is:

BUFF (I) = Station ID (BCD . . . left adjusted)
(I+1) = Time (minutes from 0 hours epoch day)
(I+2) = Range (earth radii)
(I+3) = Azimuth (radians)
(I+4) = Elevation (radians)
(I+5) = Range rate (earth radii/min)
(I+6) = σ range (earth radii)
(I+7) = σ azimuth (radians)

(I+8) = σ elevation (radians)
(I+9) = σ range rate (earth radii/min)

for 5 observations.

IBSIZE	The size of the observation record on the BCT
TEMP	A 16-cell array to hold the observation card information as output from OBSRD
TR	The end of observation indicator ENDbbb (BCD)

SUBROUTINES USED

A. Library

.FBLT. .FRWT. .FWRD.

.FCNV. .FVIO.

.FEFT. .FWLR.

.FFIL. .FWRB.

B. Program

OBSRD	Reads the observation cards
TIME	Converts Gregorian Date to Julian Date

EQUATIONS

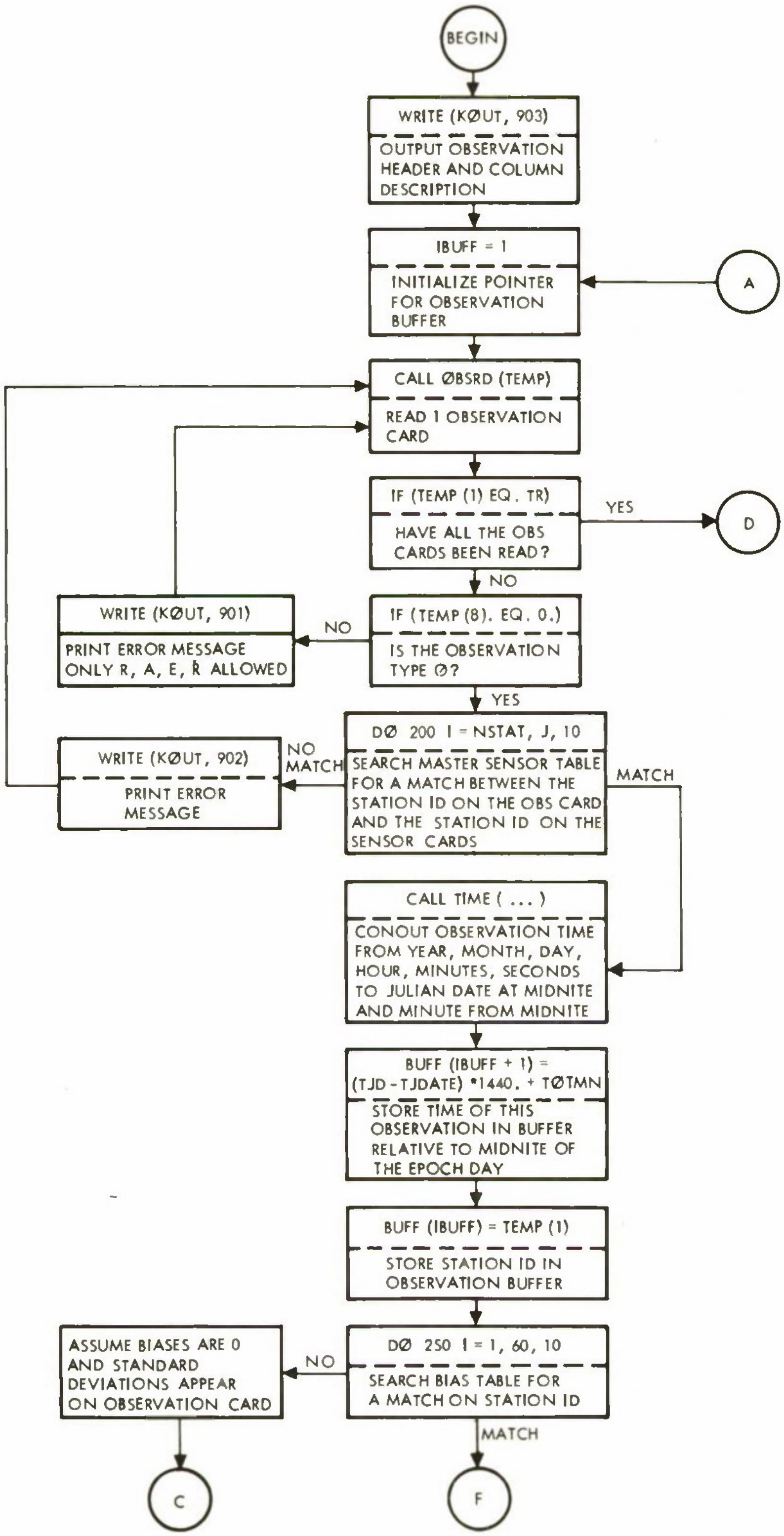


Figure 5-23. LODOBS Flow Diagram

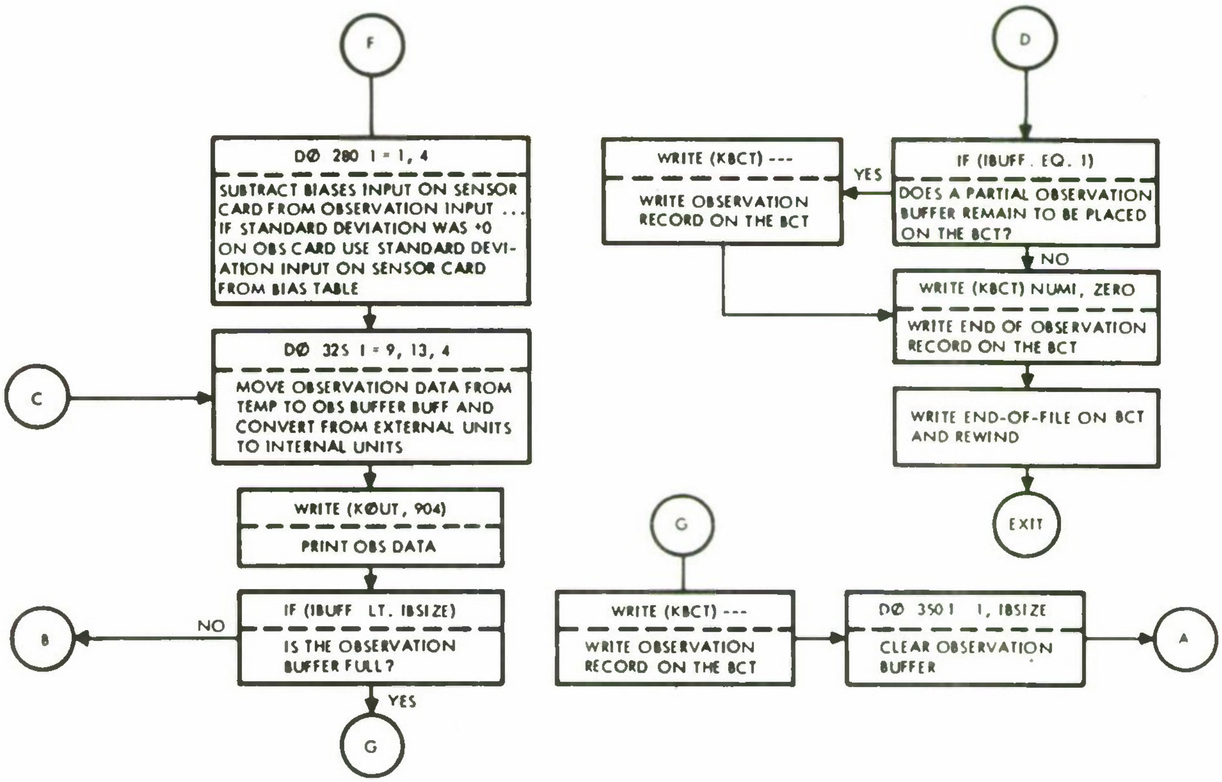


Figure 5-23. LODOBS Flow Diagram (Continued)

SUBROUTINE IDENTIFICATION

A. Title
LODOBS

B. Segment
NRTPOD - Input Processor

C. Called by subroutine
DPROS

FUNCTION

The function is to control the logic flow in loading, storing, sorting, and printing the observations to be used in the differential correction.

USAGE

A. Calling sequence
CALL LODOBS

B. Input

1. Blank COMMON

MT	Observations tape (symbolic tape no.)
KOUT	Symbolic output tape (print)
CKMER	Conversion from earth radii to kilometers (km/e. r.)
CDEG	Conversion from radians to degrees (deg/radian)
COMLST	Dimension of variable storage (2700 for NRTPOD)
PREFLG	NRTPOD control flags - columns 31-40 on the JDC card)
TEPOCH	Epoch time, minutes from midnight

2. Labeled COMMON

/TEMP/

TEMP	Temporary storage

/OBSTR/

u	Temporary storage used as a buffer for a fixed number of observations

3. Calling sequence

—

C. Output

1. Blank COMMON

NMBER	Counter on the number of observations.

2. Labeled COMMON

—

3. Calling sequence

—

D. Error/action messages

1. Off-line comment

"OBSERVATIONS OVERFLOWED COMMON, ERROR."

2. On-line comment

—

3. Action

Continues processing observations, assuming all observations are presorted.

SUBROUTINES USED

A. Library

MOD

B. Program

BCDOBS	Reads observation cards one at a time
OBSIN	Applies sensor biases, if any, and scales observation data and weights (σ's) to internal units and moves this data from temporary storage to permanent storage
OBSSRT	Sorts observations timewise with respect to the number of days from 1950.0 to the day of epoch
CLTIME	Computes the calendar date given the minutes from midnight, day of epoch
WRTOBS	Writes the observations on an intermediary observations tape (MT)
WEOFT	Writes an end-of-file record on the observations tape (MT)

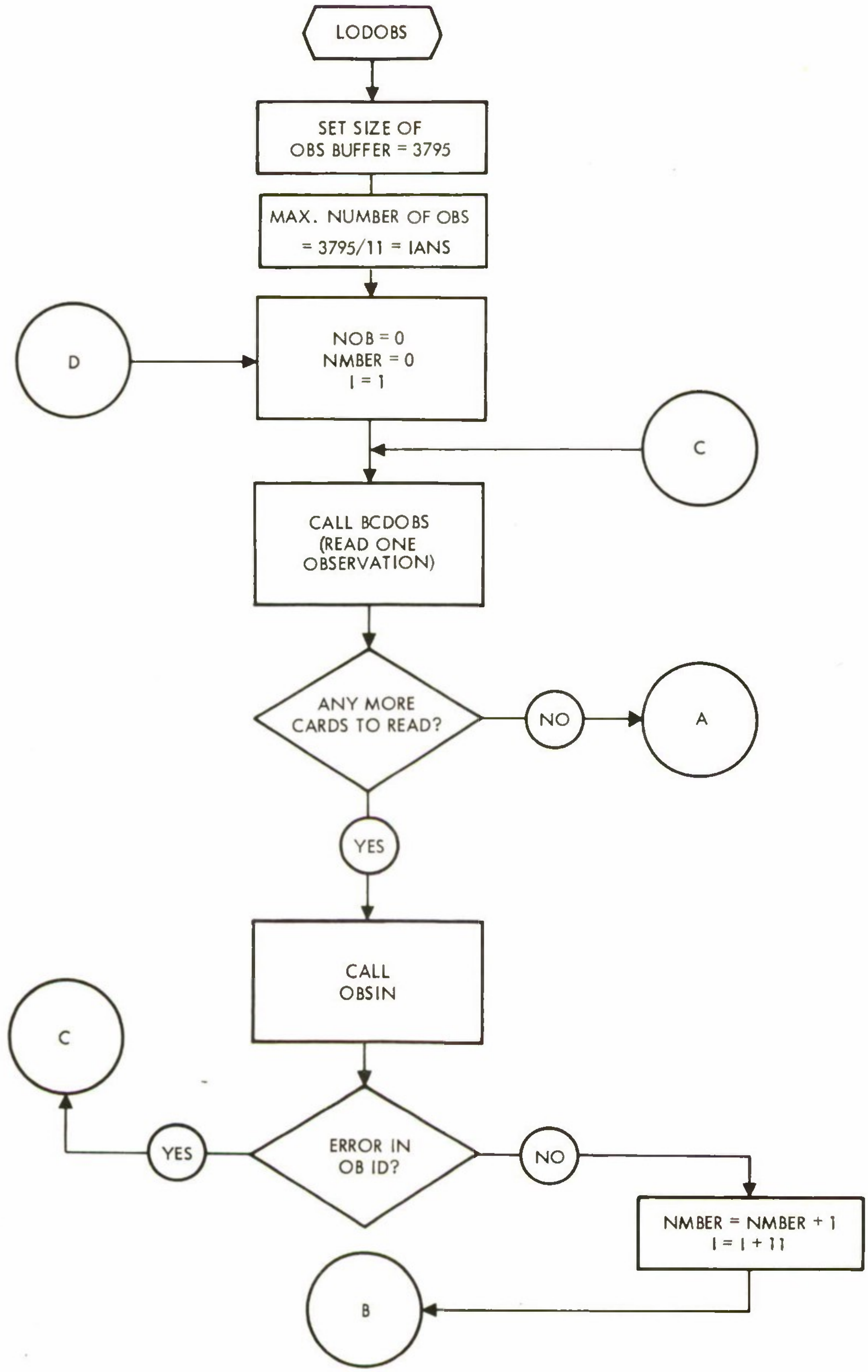


Figure 5-24. LODOBS Flow Diagram

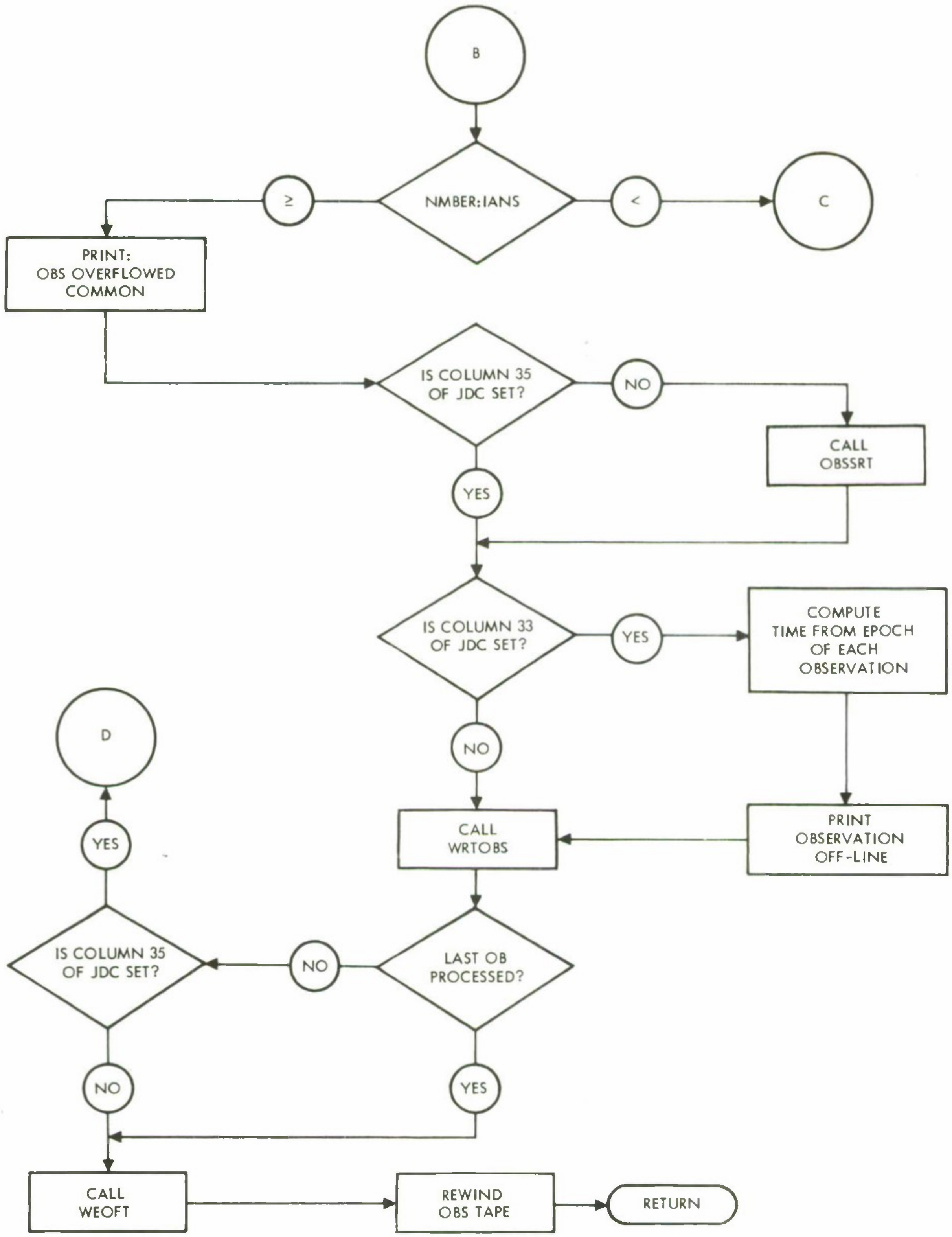


Figure 5-24. LODOBS Flow Diagram (Continued)

SUBROUTINE IDENTIFICATION

A. Title

LODSEN

B. Segment

PREMOD

C. Called by subroutine

PREMOD

FUNCTION

This is the main control for the sensor card processor. Station location cards are read and printed, the master sensor table is formed, and the BIAS table is generated.

USAGE

A. Calling sequence

Call LODSEN

B. Input

1. COMMON

KOUT	Logical number of printed output device
VSTR	Variable storage array
NSTAT	Location of master sensor table in VSTR
CDEG	Degrees per radian
CMTER	Meters per earth radii
CKMER	Kilometers per earth radii

2. Calling sequence

—

C. Output

—

D. Error/action messages

If more than six unique station ID's are processed, the following message is printed:

NO ROOM IN MASTER SENSOR TABLE FOR
STATION XX . . . CARD IGNORED

E. Internal storage

TEMP	Used to transmit the data from the sensor cards from routine SENRD
END	BCD indicator to detect station ID of END which terminates sensor card processing
FIRST	Not used
ERROR	Error indicator from subroutine SENIN indicating that the master sensor table is full

SUBROUTINES USED

A. Library

.FCNV. .FSLO. .FWRD.

.FFIL. .FVIO. .FXEM.

B. Program

SENIN	Build master sensor table
SENRD	Read sensor cards

2. Calling sequence

—

C. Output

1. COMMON

SIGMH	4-cell array containing the standard deviation in range (earth radii), azimuth (radians), elevation (radians), and range rate (earth radii/min) for the first station in the master sensor table. This station will usually be

Millstone Hill, although it may be any arbitrary station. When running MHESPOD, the σ's for the observations from DAP (assumed to be observations from Millstone) will be assumed in SIGMH.

/BIAS/

BIAS — A 60-cell array containing station information for 1-6 stations, the format is:

	BIAS (I) = ID (left adjusted . . . BCD)	Taken from sensor cards
	(I+1) = Range bias (km)	
	(I+2) = Azimuth bias (deg)	
I+1, . . . , 6	(I+3) = Elevation bias (deg)	
	(I+4) = Range rate bias (km/sec)	
	(I+5) = Not used	
	(I+6) = Range σ (km)	
	(I+7) = Azimuth σ (deg)	
	(I+8) = Elevation σ (deg)	
	(I+9) = Range rate σ (km/sec)	

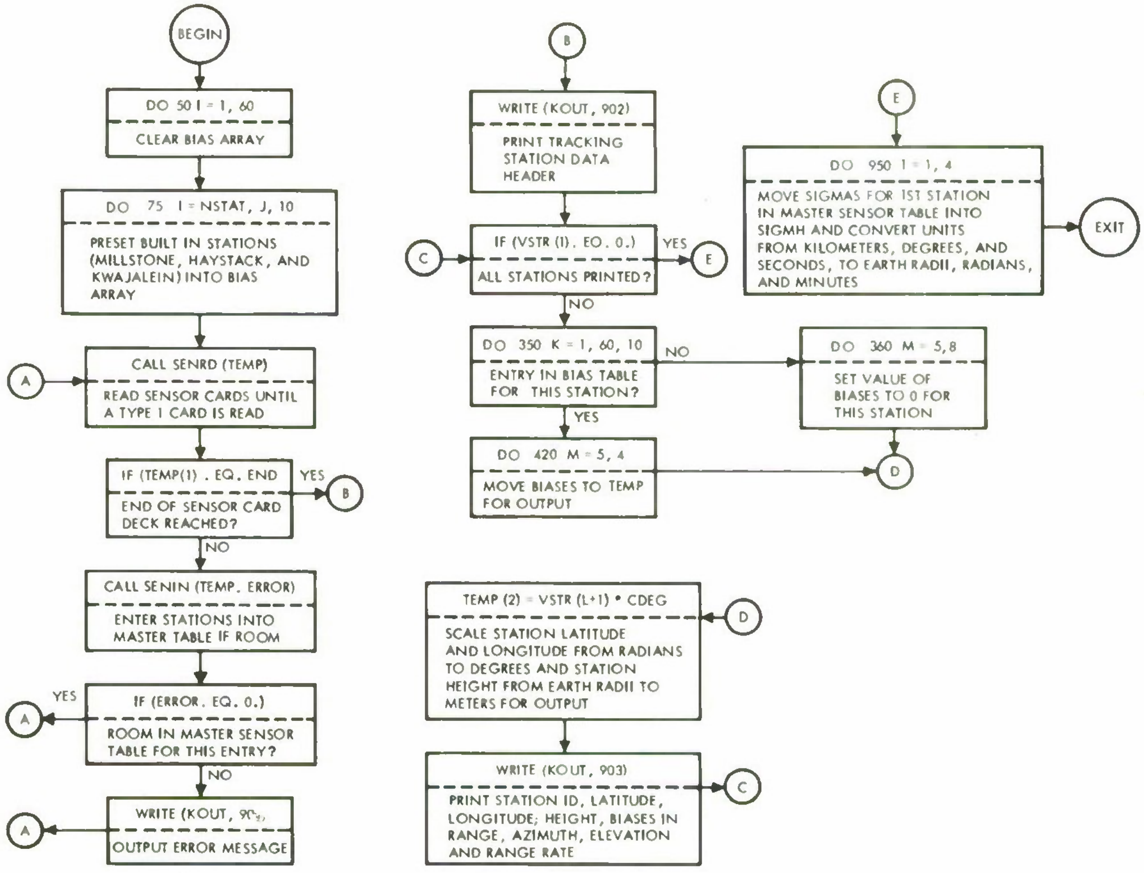


Figure 5-25. LODSEN Flow Diagram

SUBROUTINE IDENTIFICATION

A. Title

LODSEN

B. Segment

NRTPOD - Input Processor

C. Called by subroutines

DPROS

FUNCTION

The function is to clear out sensor and observation temporary storage and to control the logic flow in the loading, converting, and compacting of sensor data.

USAGE

A. Calling sequence

CALL LODSEN

B. Input

1. Blank COMMON

CKMER	Conversion from earth radii to kilometers (km/e.r.)
CDEG	Conversion from radians to degrees (deg/radian)
COMLST	Dimension of variable storage (2700 for NRTPOD)
KOUT	Symbolic output tape (print)
NSTAT	Starting location in variable storage (VSTR) of the master sensor table
NSSTB	Identifies the starting location where station information concerning weights and mean of residuals are stored
PREFLG	NRTPOD control flags (columns 31-40 on JDC card)

2. Labeled COMMON

/INPP/

NDTMP	Counter on DTMP buffer for biases and weights by station
DTMP	Buffer storage for biases and weights by station

3. Calling sequence

—

C. Output

1. Blank COMMON

NUBS	Starting location of the observation table in VSTR

2. Labeled COMMON

—

3. Calling sequence

—

D. Error/action messages

1. Off-line comment

"SENSOR DATA OVERFLOWS COMMON, ERROR"

2. Action

Calls EXIT

SUBROUTINES USED

A. Library

EXIT	Exit routine

B. Program

SENRD	Reads the sensor cards (3 types) and builds a temporary buffer of biases and weights by station.
SENIN	Scales sensor information and moves this information from buffer storage to working storage. SENIN also sets up the master sensor table with correct units and values.

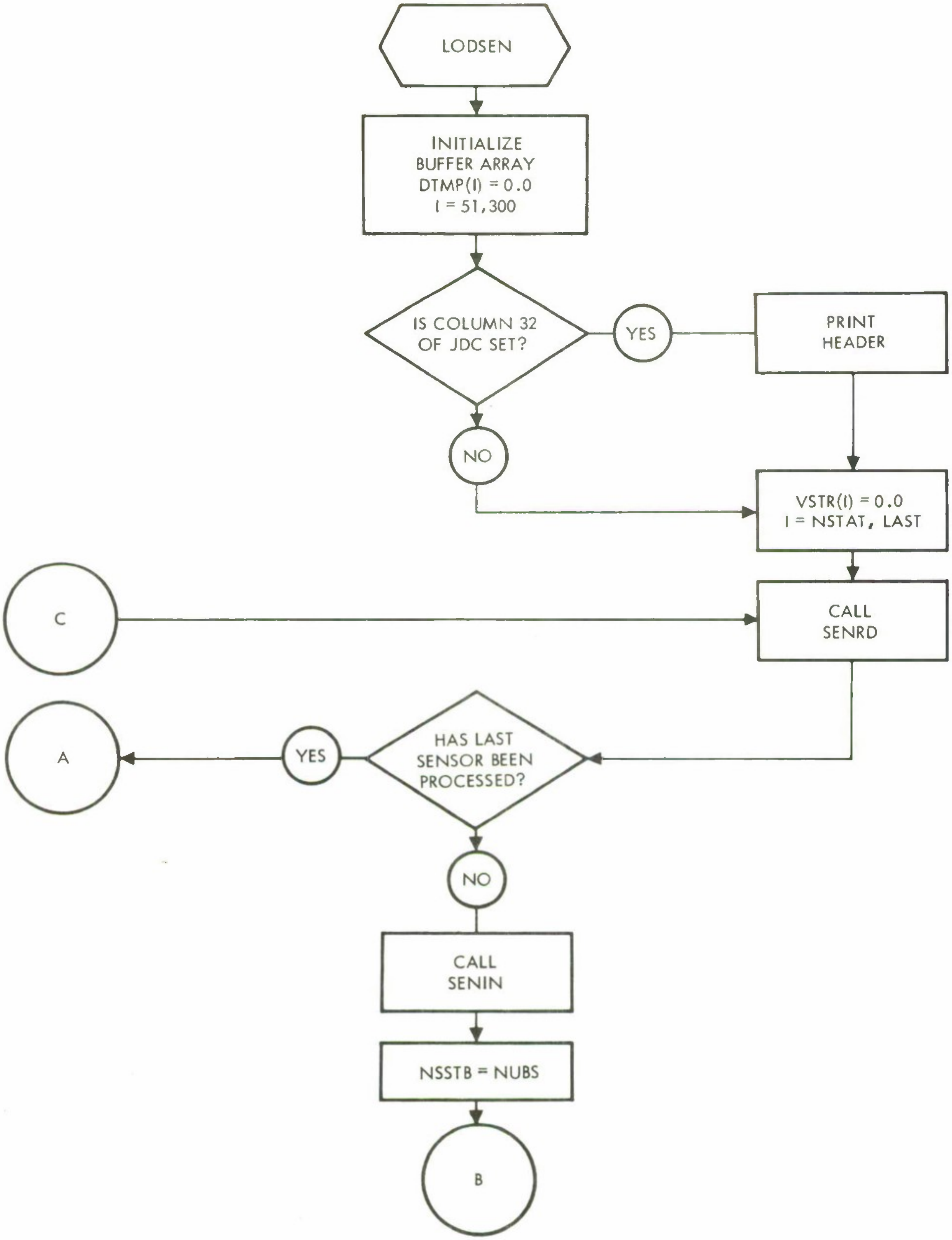


Figure 5-26. LODSEN Flow Diagram

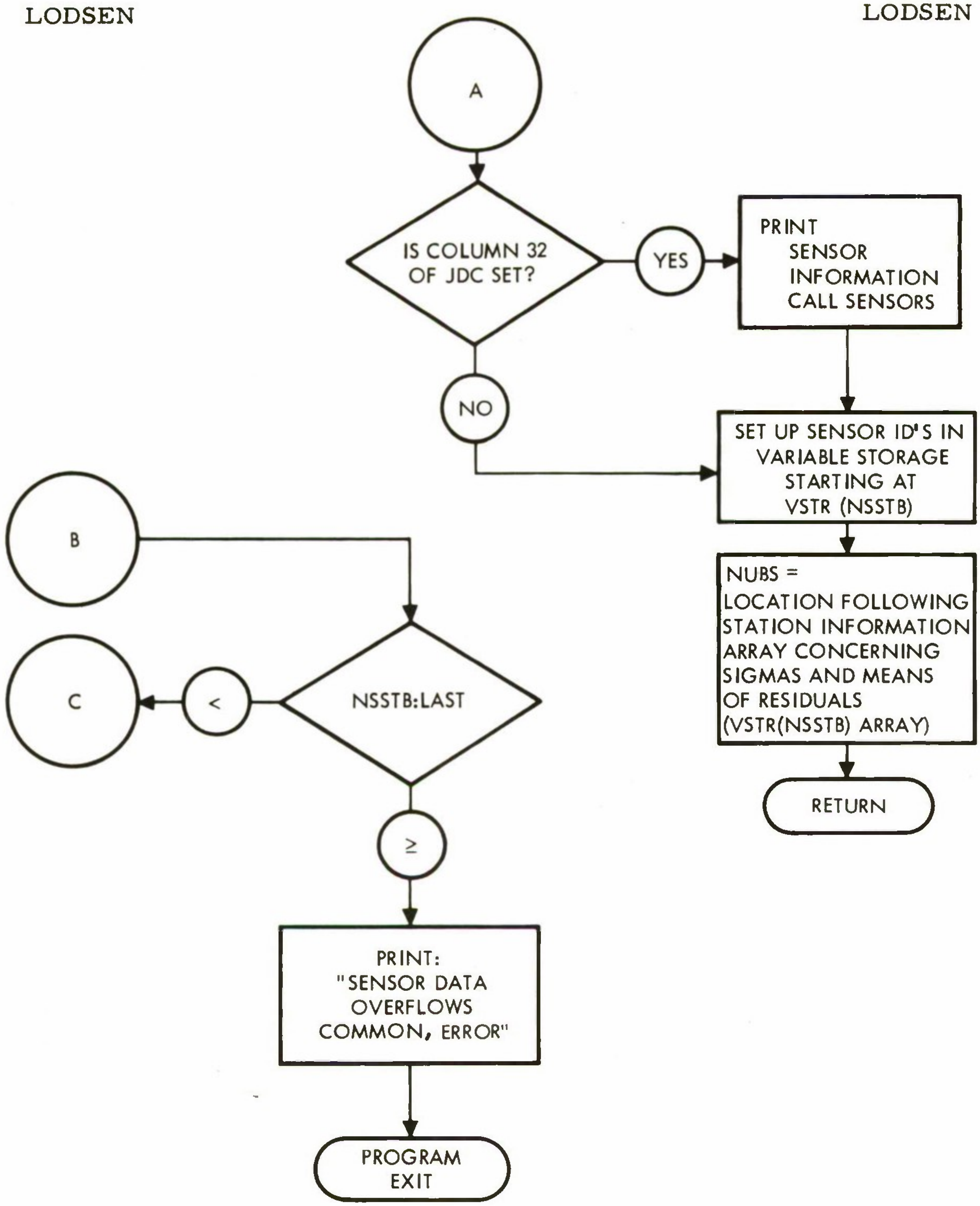


Figure 5-26. LODSEN Flow Diagram (Continued)

SUBROUTINE IDENTIFICATION

A. Title

MABAT

B. Segment

NRTPOD
PREMOD

C. Called by subroutine

PRAUPD

FUNCTION

The function is to compute $R^* = URU^T$, where U is an N1 x N2 full matrix and R is an N2 x N2 lower triangular matrix. The result, R*, will be a N1 x N1 lower triangular matrix.

USAGE

A. Calling sequence

CALL MABAT (U, R, RS, I4, I5)

B. Input

1. COMMON

—

2. Calling sequence

U	Starting location of the U matrix
R	Starting location of the R matrix
I4	Matrix RS is I4 by I4 lower triangular
I5	Matrix R is I5 by I5 lower triangular

C. Output

1. COMMON

—

2. Calling sequence

RS	Starting location of the R* matrix

D. Error/action messages

—

MABAT

SUBROUTINES USED

A. Library

—

B. Program

—

SUBROUTINE IDENTIFICATION

A. Title

MATCH

B. Segment

MHESPOD
NRTPOD

C. Called by subroutine

PARSET

SSTB, SENIN — NRTPOD segement only

FUNCTION

Performs a logical comparison of two floating point variables.

USAGE

A. Calling sequence

C = MATCH (A, B) (FUNCTION SUBPROGRAM)

B. Input

1. COMMON

—

2. Calling sequence

A, B variables to be compared

C. Output

1. COMMON

—

2. Calling sequence (function subprogram)

$C = 0$ if $A = B$
$= 1$ if $A \neq B$

D. Error/action messages

—

SUBROUTINES USED

A. Library

—

B. Program

—

SUBROUTINE IDENTIFICATION

A. Title

MATPT

B. Segment

NRTPOD
PREMOD

C. Called by subroutine

PRAUPD
PRTATA
APPLY

FUNCTION

To print a lower triangular matrix of dimension N2, with the first element at A (N1). A fixed or floating point print format is optional.

USAGE

A. Calling sequence

CALL MATPT (A, N1, N2, N3)

B. Input

1. COMMON

TEMP	Temporary storage
KOUT	Symbolic output tape

2. Calling sequence

A	Lower triangular matrix to be printed
N1	First element stored at A (N1)
N2	Dimension of matrix A
N3	Flag to indicate desired print format
	N3 = 0 Prints using floating point format
	N3 $\neq$ 0 Prints using fixed point format

C. Output

1. COMMON

—

2. Calling sequence

—

D. Error/action messages

—

SUBROUTINES USED

A. Library

—

B. Program

—

SUBROUTINE IDENTIFICATION

A. Title

MOVEVS

B. Segment

NRTPOD

C. Called by subroutines

UBSGET

FUNCTION

This subroutine moves the next observation set from variable storage to working storage (PUBS). The weights (σ's) of the observations are moved into the sigma working storage (PSIG).

USAGE

A. Calling sequence

CALL MOVEVS (J)

B. Input

1. COMMON

VSTR (NUBS)	Array containing observation sets

2. Calling sequence

J	Index for the next observation set to be picked up out of array VSTR (NUBS)

C. Output

1. COMMON

PUBS (1)	Sensor ID
PUBS (2)	Observation time, min from 0^h day of epoch
PUBS (3)	Range (e.r.)
PUBS (4)	Azimuth (rad)
PUBS (5)	Elevation (rad)
PUBS (6)	Range rate (e.r./min)
PUBS (7)	Observation type
PSIG (1)	σ_R (e.r.)
PSIG (2)	σ_A (rad)
PSIG (3)	σ_E (rad)
PSIG (4)	$\sigma_{\dot{R}}$ (e.r./min)

MOVEVS

2. Calling sequence

—

D. Error/action messages

—

SUBROUTINES USED

A. Library

—

B. Program

—

SUBROUTINE IDENTIFICATION

A. Title

MTOC

B. Segment

PREMOD

C. Called by subroutine

DPRLM

FUNCTION

To update a set of Smithsonian mean elements, convert to osculating and then to Cartesian. It also calls JTOC to convert the Julian date to calendar date.

USAGE

A. Calling sequence

Call MTOC (TNOMX, SMELM, DELT)

B. Input

1. COMMON

DAYINT	Integer portion of Julian date
DAYFRC	Fractional portion of Julian date
CJ2	J2 earth harmonic
C2PI	2π radians
CPI	π radians
KOUT	Output tape unit
CMU	μ ER^3/min^2
CKMER	Conversion from kilometers to earth radii

2. Calling sequence

SMELM	21-word vector containing the Smithsonian mean elements and their time derivatives for updating and conversion to osculating. See Table I.

Table I

Location	Element	Units
SMELM (1)	a	earth radii
(2)	e	--
(3)	i	radians
(4)	Ω	radians
(5)	ω	radians
(6)	M	radians
(7)	$\dot{a}$	er/day
(8)	$\dot{e}$	--/day
(9)	$\dot{i}$	rad/day
(10)	$\dot{\Omega}$	rad/day
(11)	$\dot{\omega}$	rad/day
(12)	n	rad/day
(13)	$\ddot{a}/2$	er/day^2
(14)	$\ddot{e}/2$	--/day^2
(15)	--	--
(16)	$\ddot{\Omega}/2$	rad/day^2
(17)	$\ddot{\omega}/2$	rad/day^2
(18)	$\dot{n}/2$	rad/day^2
(19)	$\ddot{n}/6$	rad/day^3
(20)	$\dddot{n}/24$	rad/day^4

DELT Time to epoch in days, should be greater than 10^{-8} or else set to zero identically

C. Output

1. COMMON

DYEAR Calendar year - 1900
DMNTH Calendar month

DDAY	Calendar day	MCOM (54)
DHOUR	Hour	MCOM (55)
DMIN	Minute	MCOM (56)
DSEC	Second	MCOM (57)

2. Calling sequence

TNOMX	6-word vector containing x, y, z, $\dot{x}$, $\dot{y}$, $\dot{z}$ in kilometers and kilometers/second
TNOMX(1)	x kilometers
TNOMX(2)	y kilometers
TNOMX(3)	z kilometers
TNOMX(4)	$\dot{x}$ kilometers/second
TNOMX(5)	$\dot{y}$ kilometers/second
TNOMX(6)	$\dot{z}$ kilometers/second

D. Error/action messages

E FAILED TO CONVERGE
THE VALUE OF E IS______E___, THE FLAG IS________

This message occurs if the iteration for E has failed to converge after 50 iterations. The flag = 0 indicates the iteration failed for conversion to osculating of the mean elements. The flag = 1 indicates the iteration failed for conversion to Cartesian of the osculating. The program proceeds normally.

SUBROUTINES USED

A. Library

ABS

SIN

COS

ATNQ

SQRT

B. Program

PIMOD	Takes principal value of angle between 0 and 2π

DLSTV	Computes the differentials used in converting from mean to osculating and osculating to mean
JTOC	Converts Julian date to calendar date

EQUATIONS

Given $a_{m_{K-25}}$, e_m, i_m, Ω_m, ω_m, M_m

1. Compute E using

$$E_1 = \pi$$

$$E_{n+1} = E_n + \frac{M_m - E_n + e_m \sin E_n}{1 - e_m \cos E_n}$$

2. Compute true anomaly, v

$$\cos v = \frac{\cos E - e_m}{1 - e_m \cos E}$$

$$\sin v = \frac{\sqrt{1 - e_m^2} \sin E}{1 - e_m \cos E}$$

3. Compute radius vector

$$r = a_{m_{k-25}} (1.0 - e_m \cos E)$$

4. Compute orbital semi-parameter

$$p_m = a_{m_{K-25}} (1 - e_m^2)$$

5. Obtain δ's from DLSTV

6. Compute a_m

$$a_m = \frac{a_{m_{K-25}}}{\left[1 - A_2/p_m (1 - 3/2 \sin^2 i_m) \sqrt{1 - e^2_m}\right]}$$

7. Compute osculating elements

$$a_{os} = a_m + \delta_{a_m} (a_{m_{K-25}}, e_m, i_m, \Omega_m, \omega_m, M_m)$$

$$e_{os} = e_m + \delta_{e_m} (a_{m_{K-25}}, e_m, i_m, \Omega_m, \omega_m, M_m)$$

$$i_{os} = i_m + \delta_{i_m} (a_{m_{K-25}}, e_m, i_m, \Omega_m, \omega_m, M_m)$$

$$\Omega_{os} = \Omega_m + \delta_{\Omega_m} (a_{m_{K-25}}, e_m, i_m, \Omega_m, \omega_m, M_m)$$

$$\omega_{os} = \omega_m + \delta_{\omega_m} (a_{m_{K-25}}, e_m, i_m, \Omega_m, \omega_m, M_m)$$

$$M_{os} = M_m + \delta_{M_m} (a_{m_{K-25}}, e_m, i_m, \Omega_m, \omega_m, M_m)$$

8. Convert to Cartesian

a. Obtain E and v as above

$$u = v + \omega$$

$$\ell = u + \Omega_{os}$$

$$\ell_r = u - \Omega_{os}$$

b. $U_x = 1/2 ((1 + \cos i_{os}) \cos \ell + (1 - \cos i_{os}) \cos \ell_r)$

$U_y = 1/2 ((1 + \cos i_{os})$

$U_z = \sin u \sin i_{os}$

$V_x = -1/2\ ((1 + \cos i_{os}) \sin \ell + (1 - \cos i_{os}) \sin \ell_r)$

$V_y = 1/2\ ((1 + \cos i_{os}) \cos \ell + (1 - \cos i_{os}) \cos \ell_r)$

$V_z = \cos u \sin i_{os}$

c. $r = a_{os} * (1 - e_{os} * \cos E)$

$\dot{r} = (\sqrt{\mu a_{os}})\ (e_{os} \sin E)/r$

$r\dot{v} = (\sqrt{\mu a_{os}})\ (\sqrt{1 - e_{os}^2})/r$

d. $x = rU_x$

$y = rU_y$

$z = rU_z$

$\dot{x} = \dot{r}U_x + r\dot{v}V_x$

$\dot{y} = \dot{r}U_y + r\dot{v}V_y$

$\dot{z} = \dot{r}U_z + r\dot{v}V_z$

SUBROUTINE IDENTIFICATION

A. Title

NRTPOD

B. Segment

NRTPOD - INPUT PROCESSOR

C. Called by subroutine

Main driver for NRTPOD control

FUNCTION

Main control for NRTPOD

USAGE

A. Calling sequence

-

B. Input

1. COMMON

//BLK1, BLK2, BLK3, BLK4	Blank COMMON blocks
/VSTR/	Variable storage
/EPHCOM/	Lunar-solar ephemeris cells
/TEMP/	Temporary storage
PREFLG	JDC options flag columns 31-40
DCFLG	JDC options flag columns 41-50
PSTFLG	JDC options flag columns 51-60

2. Calling sequence

-

C. Output

1. COMMON

-

2. Calling sequence

-

D. Error/action messages

-

NRTPOD

SUBROUTINES USED

A. Library

-

B. Program

INPUT
TRJPRO

EQUATIONS

None

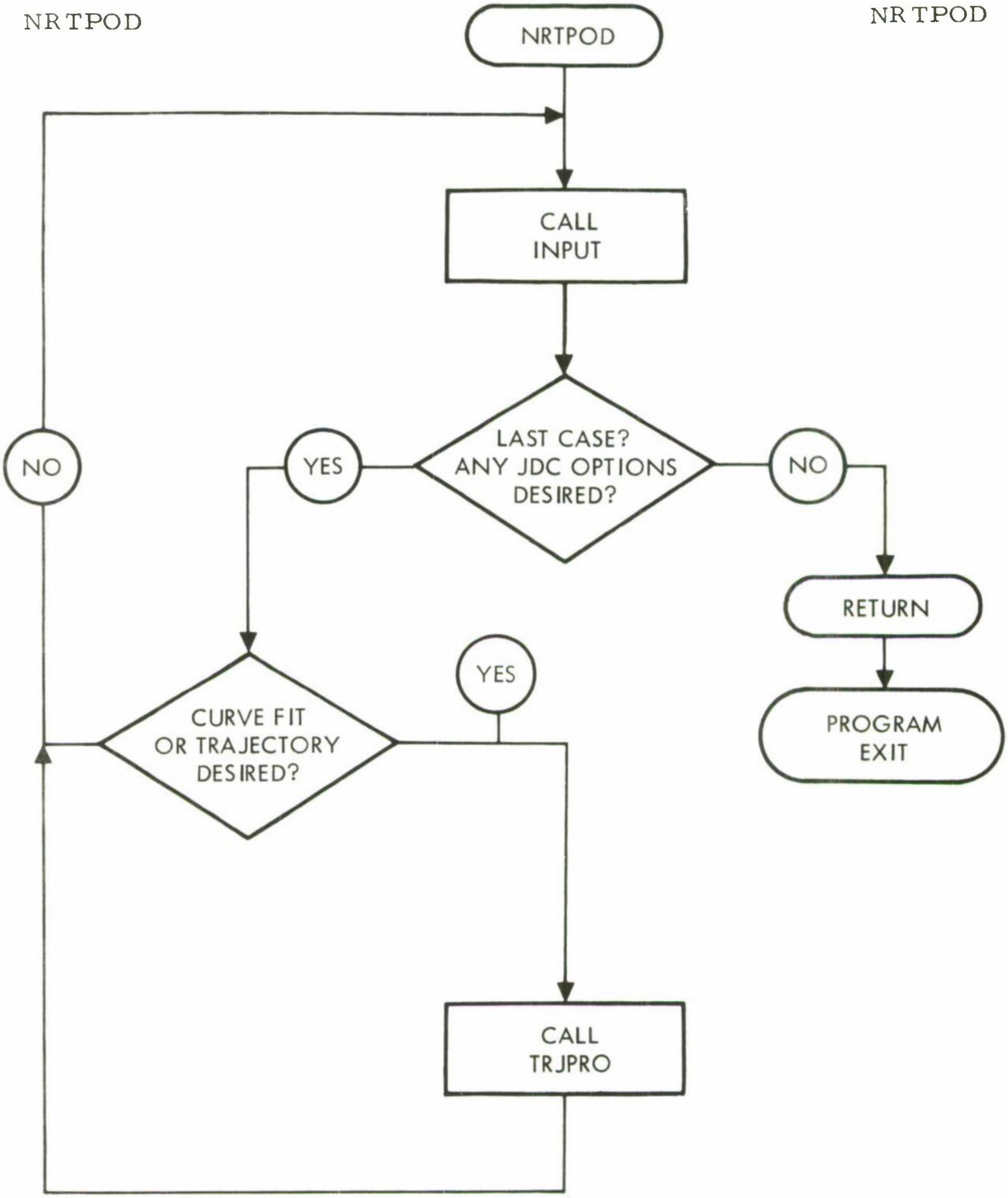


Figure 5-27. NRTPOD Flow Diagram

SUBROUTINE IDENTIFICATION

A. Title

OBSIN

B. Segment

NRTPOD - Input Processor

C. Called by subroutine

LODOBS

FUNCTION

Function is to apply sensor biases, if any, scale observation data and weights (σ 's) to internal units, and move this data from temporary storage to permanent storage (Z). This routine overrides the weights input on sensor cards by the weights, if any, input on the observation cards.

USAGE

A. Calling sequence

CALL OBSIN (Z, ISTART, NOB)

B. Input

1. Blank COMMON

CKMER	(km/e. r.)
CDEG	(Deg/radian)
KOUT	Output type number
NSSTB	VSTR pointer for station mean and RMS information
NSTAT	VSTR pointer for master sensor table
TJDATE	Julian date of midnight, epoch day

2. Labeled COMMON

/TEMP/

TEMP (1)	Station ID
TEMP (2-7)	Time of observation in year, month, day, hour, minute, second
TEMP (9)	R range
TEMP (10)	A azimuth (rad)
TEMP (11)	E elevation (rad)
TEMP (12)	$\dot{R}$ range rate (e. r. /min)
TEMP (8)	type
TEMP (13)	σ_R standard deviation in range (e. r.)
TEMP (14)	σ_A standard deviation in azimuth (rad)
TEMP (15)	σ_E standard deviation in elevation (rad)
TEMP (16)	$\sigma_{\dot{R}}$ Standard deviation in range rate (e. r. /min)

/INPP/	
NDTMP	Counter on the DTMP buffer for biases and weights by station
DTMP	Buffer storage for station and observation biases along with their respective weights (σ's)
/VSTR/	
VSTR	Variable storage array

3. Calling sequence

ISTART	Starting location of Z

C. Output

1. COMMON

-

2. Calling sequence

Z (ISTART)	Station ID
Z (ISTART +1)	Time from epoch (min)
Z (ISTART +2)	R, range (e. r.)
Z (ISTART +3)	A, azimuth (rad)
Z (ISTART +4)	E, elevation (rad)
Z (ISTART +5)	$\dot{R}$, range rate (e. r. /min)
Z (ISTART +6)	Type
Z (ISTART +7)	σ_R, standard deviation in range (e. r.)
Z (ISTART +8)	σ_A, standard deviation in azimuth (rad)
Z (ISTART +9)	σ_E, standard deviation in elevation (rad)
Z (ISTART +10)	$\sigma_{\dot{R}}$, standard deviation in range rate (e. r. /min)
NOB	Flag to indicate error in observation ID. =0 ID found in master sensor table. ≠0 ID not found in master sensor table.

D. Error/action messages

1. Off-line comment

"ERROR IN OBSERVATION ID____"

2. On-line comment

—

3. Action

Set NOB flag, return to calling program.

SUBROUTINES USED

A. Library

-

B. Program

TIME - Computes Julian date and minutes from midnight of epoch day

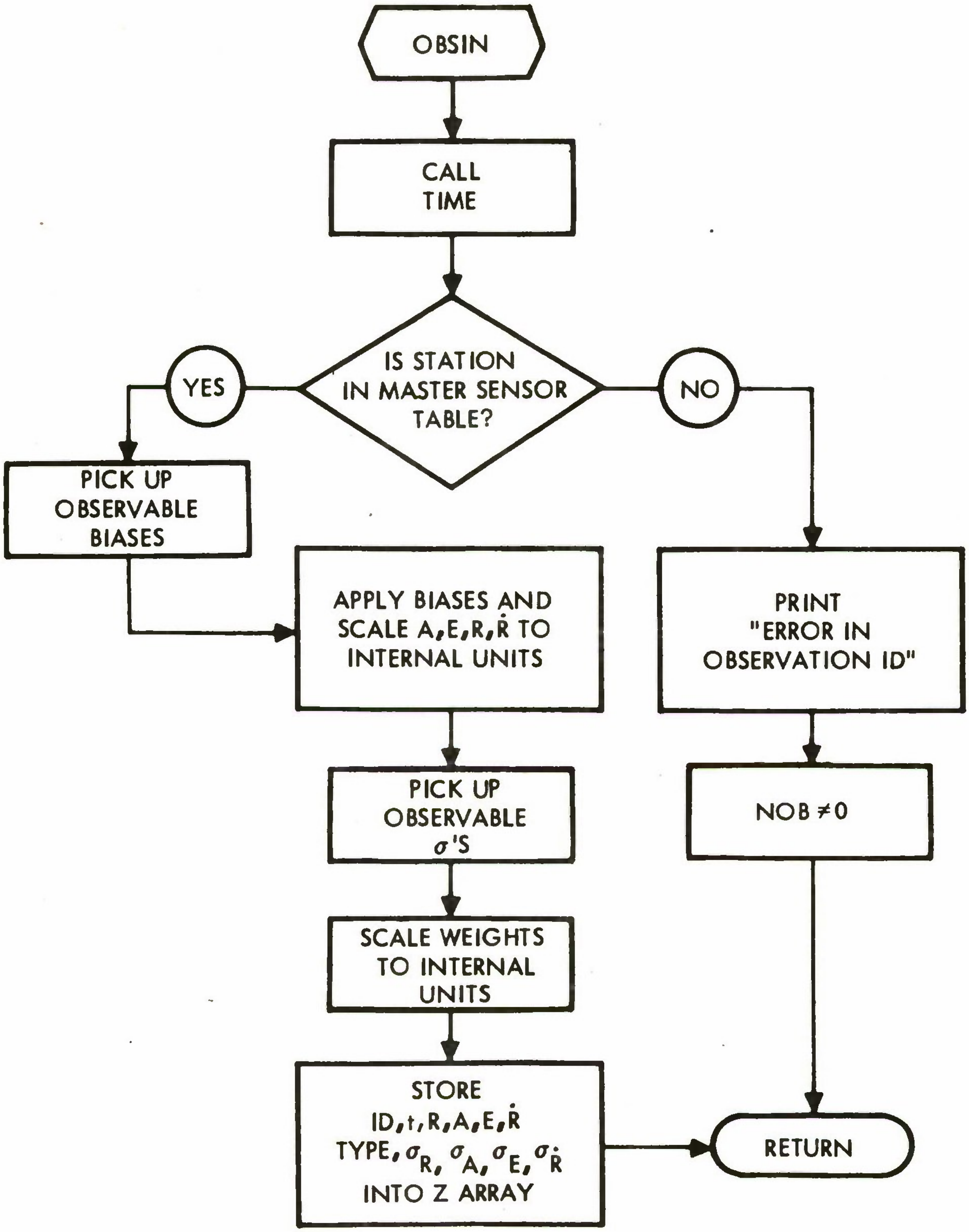


Figure 5-28. OBSIN Flow Diagram

SUBROUTINE IDENTIFICATION

A. Title

OBSRD

B. Segment

PREMOD

C. Called by subroutine

LODOBS

FUNCTION

To read an observation card in the MHESPOD format. (See card format description below.)

USAGE

A. Calling sequence

Call OBSRD (A)

B. Input

1. COMMON

KIN	Logical number of the input device

2. Calling sequence

—

C. Output

1. COMMON

—

2. Calling sequence

A	A 16-cell unit containing the following information from the observation card:
A(1)	Station ID (left adjusted . . . BCD)

A(2)	Year number - 1900
A(3)	Month
A(4)	Day
A(5)	Hour
A(6)	Minute
A(7)	Second
A(8)	Type (= 0)
A(9)	Range (km)
A(10)	Azimuth (deg)
A(11)	Elevation (deg)
A(12)	Range rate (km/sec)
A(13)	σ range (km)
A(14)	σ azimuth (deg)
A(15)	σ elevation (deg)
A(16)	σ range rate (km/sec)

D. Error/action messages

—

E. Internal Storage

T — A 4-cell array to hold the exponent for the σ entries on the observation cards. The ordering is range, azimuth, elevation, range rate.

SUBROUTINES USED

A. Library

.FCNV. .FRTN. .XP3.

.FRDD. .FVIO.

B. Program

—

EQUATIONS

The sigmas for each data type are given as three columns on the observation cards. Two columns are used to specify the sigma as an integer $X10^{-5}$, the third column is a positive exponent of 10 to be used as a scaling factor.

If the integer is I, the scaling factor S then $\sigma = I \times 10^{(s-5)}$

CARD FORMAT

Column	Description
1-3	Station ID
4-6	Not used
7-8	Year - 1900
9-10	Month
11-12	Day
13-14	Hour
15-16	Minute
17-25	Second (Decimal assumed between 19 and 20 if omitted)
26	Type (= 0)
27-34	Azimuth (deg) . . . decimal assumed between 29 and 30 if omitted
35-36	σ integer part x 10^{-5} azimuth
37	σ scaling factor . . . power of ten (0 - 9)
38-46	Elevation (deg) . . . decimal assumed between 41 and 42 if omitted
47-49	σ elevation in packed format (see azimuth above)
50-62	Range (km) . . . decimal assumed between 58 and 59 if omitted
63-65	σ range in packed format
66-75	Range rate (km/sec) . . . decimal assumed between 70 and 71 if omitted
76-78	σ range rate in packed format
79-80	Not used

SUBROUTINE IDENTIFICATION

A. Title

OBSSRT

B. Segment

NRTPOD - Input Processor

C. Called by subroutine

LODOBS

FUNCTION

Function is to sort the observations time wise with respect to epoch time. All observations taken before epoch are sorted with respect to epoch ahead of observations taken after epoch.

USAGE

A. Calling sequence

CALL OBSSRT (A, ISTART, IFINAL)

B. Input

1. Blank COMMON

TEPOCH	Time, in minutes from 0 hours, day of epoch; the time of the initial conditions of the trajectory
DBASE	Number of days from 1950.0 to day of epoch
DHOUR	Number of hours from 0 hours, day of epoch; epoch hours
DMIN	Epoch minutes
DSEC	Epoch seconds

2. Labeled COMMON

-

3. Calling sequence

A	Array of storage to be time sorted
ISTART	Identifier for starting location of array in A storage
IFINAL	Identifier for ending location of array in A storage

C. Output

1. Blank COMMON

   -

2. Labeled COMMON

   -

3. Calling sequence

   A - Sorted array

D. Error/action messages

   -

SUBROUTINES USED

A. Library

   -

B. Program

   -

SUBROUTINE IDENTIFICATION

A. Title

OUTER

B. Segment

MHESPOD
PREMOD
NRTPOD

C. Called by subroutine

BODY
DRAG
VAREQ

FUNCTION

Function is to compute the "outer product," i. e., the 3 x 3 matrix product, which results when a 3 x 1 column vector is multiplied times a 1 x 3 row vector.

USAGE

A. Calling sequence

Call OUTER (A, I, B, J, C)

B. Input

1. COMMON

—

2. Calling sequence

A Address of the 3 x 1 column vector array
I Location of first element in A
B Address of 1 x 3 row vector array
J Location of first element in B

C. Output

1. COMMON

—

2. Calling sequence

C Address of 3 x 3 array to which the outer product is added

D. Error/action messages

—

OUTER

SUBROUTINES USED

A. Library

—

B. Program

—

EQUATIONS

None

SUBRØUTINE IDENTIFICATIØN

A. Title

PAGE1

B. Segment

MHESPØD

C. Called by subroutines

MESPØD

RADR

FUNCTIØN

Accumulates five (5) residuals and outputs these residuals on the ADT tape. Each residual is written on the ADT in the following format:

ID, t, ΔR, ΔA, ΔE, $\Delta\dot{R}$, ϕ, λ, h, $R/\dot{R}$

USAGE

A. Calling sequence

CALL PAGE1 (LAST)

B. Input

1. CØMMØN

/MESCØM/

CWE		Earth's rotational rate
IRESFG		Flag for writing residuals on ADT = 0 don't write residuals ≠ 0 write residuals
KADT		ADT tape number
PRESD		Reasiduals (measured - computed)
PUBS		Sensor ID, time, R, A, E, $\dot{R}$ table
PUI		Vector (u_1, u_2, u_3)
PWDTI		Vector ($\dot{w}_1$, $\dot{w}_2$, $\dot{w}_3$)
TALFAG		α_g for midnight, day of epoch angle between Greenich and vernal equinox
TALT		Altitude of vehicle (ft)
TRAJX	(1)	x
	(2)	y
	(3)	z
	(4)	$\dot{x}$
	(5)	$\dot{y}$
	(6)	$\dot{z}$

 PAGE1

2. Calling sequence

   LAST = 0 indicates not last iteration

   ≠ indicates last iteration

C. Output

1. CØMMØN

   TEMP Temporary storage

   /RESBUF/ Buffer to accumulate 5 residuals

2. Calling sequence

   —

D. Error/action messages

SUBROUTINES USED

A. Library

   SQRT

B. Program

   ATNQ

   PIMØD

EQUATIONS

$$\varphi = \tan^{-1}\left[\frac{z}{(x^2+y^2)^{1/2}}\right]$$

$$= \tan^{-1}\left(\frac{y}{x}\right) - (\alpha_g + \omega et)$$

$$\dot{R} = \bar{u} \cdot \bar{w}$$

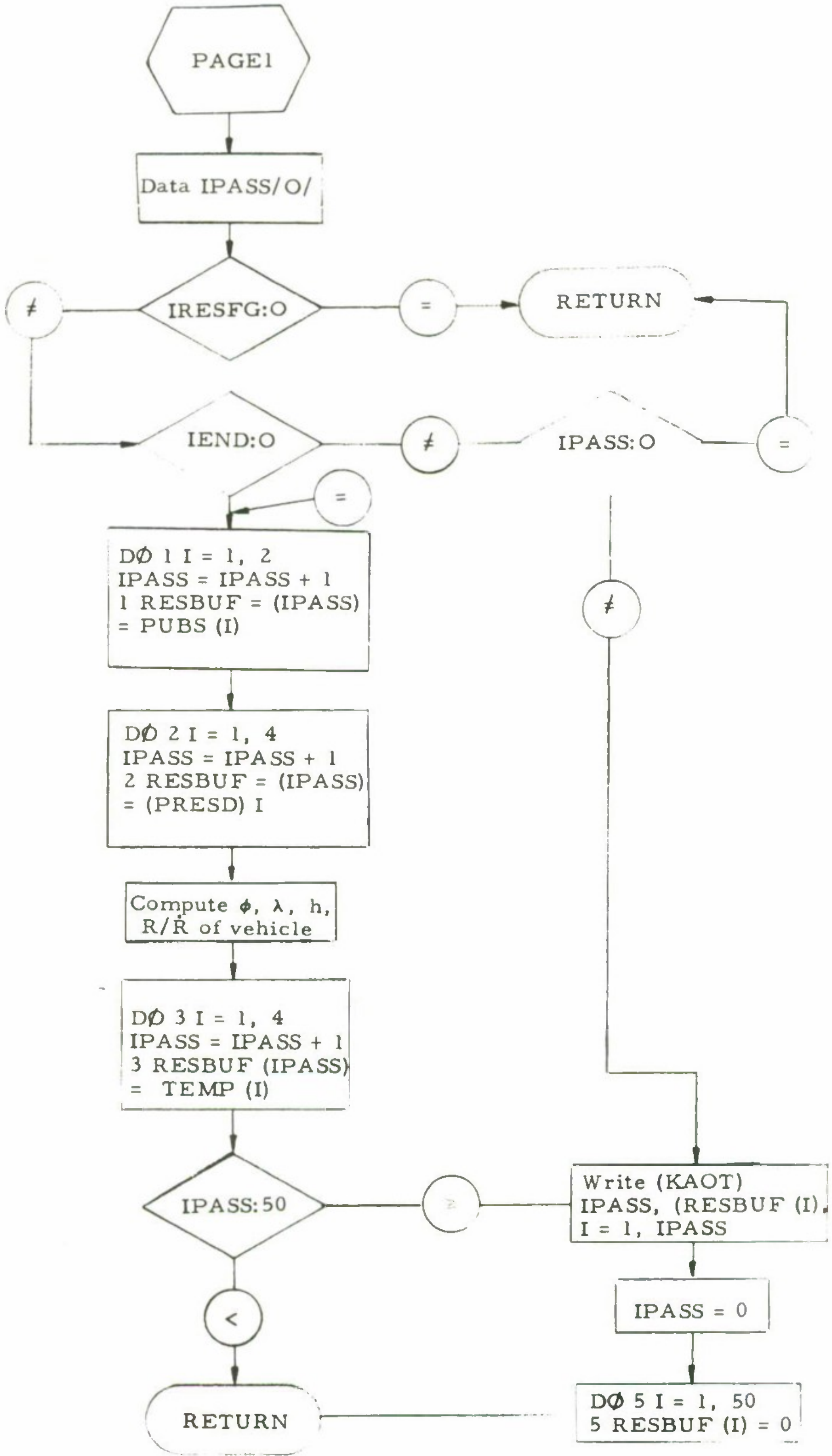


Figure 5-29. PAG1 Flow Diagram

SUBROUTINE IDENTIFICATION

A. Title

PAGE1

B. Segment

NRTPOD - partials - least square

C. Called by subroutines

RADR

FUNCTION

PAGE1 converts a line of residuals to external units and prints it.

USAGE

A. Calling sequence

Call PAGE1

B. Input

1. COMMON

CKMER	Kilometers per earth radius
CDEG	Degrees per radian
KOUT	Peripheral output tape
TEPOCH	Minutes from midnight day of epoch to epoch
PUBS	Storage for observation data
PDELFG	BCI flag for rejection type
PRESDT(9)	Residuals in internal units
IRCNT(4)	Residual number for R, A, E, $\dot{R}$

2. Calling sequence

—

C. Output

One line of formated residuals in R, A, E, $\dot{R}$, U, V, W, VM, BETA

SUBROUTINES USED

A. Library

. FCNV.

. FFIL.

.FVIO.

. FWRD.

B. Program

RMAX

SUBROUTINE IDENTIFICATION

A. Title

PAROUT

B. Segment

NRTPOD - partials - least square

C. Called by subroutine

RADR

FUNCTION

PAROUT, given right ascension of the sensor and position and velocity of the vehicle, computes residuals in an up, down, cross coordinate system.

USAGE

A. Calling sequence

CALL PAROUT

B. Input

1. COMMON

TRAJX(6)	State vector of vehicle at observation time
PUBS(7)	Observation data
PCSALF	Cos α, α = station right ascension
PSNALF	Sin α
PCMR	Computed range measurement
PWI(3)	(W_1, W_2, W_3)

C. Output

PWI(3)	(W_1, W_2, W_3)
PWDTI(3)	$(\dot{W}_1, \dot{W}_2, \dot{W}_3)$
PRESDT(5)	ΔU
(6)	ΔV
(7)	ΔW
(8)	$\sqrt{V\ (\Delta U)^2 + (\Delta V)^2 + (\Delta W)^2}$
(9)	β - out-of-plane angle

SUBROUTINES USED

1. Library

—

2. Program

DOT
RADSQ
XCROSS
YRAE
ASIN

EQUATIONS

$$\dot{W} = (\dot{W}_1, \dot{W}_2, \dot{W}_3)$$

where

$$\dot{W}_1 = \dot{x} \cos \alpha + \dot{y} \sin \alpha$$

$$\dot{W}_2 = \dot{x} \sin \alpha + \dot{y} \cos \alpha$$

$$\dot{W}_3 = \dot{z}$$

Compute u, v, w ($\overrightarrow{UP}$, $\overrightarrow{DOWN}$, $\overrightarrow{CROSS}$)

$$\mu = W \cdot \dot{W}$$

$$\overrightarrow{DOWN} = \left(\dot{W} - \mu \frac{W}{|W|^2}\right) / |\overrightarrow{DOWN}|$$

$$\overrightarrow{UP} = \frac{W}{|W|}$$

$$\overrightarrow{CROSS} = \overrightarrow{UP} \times \overrightarrow{DOWN}$$

If range measurement R not available use computed value and find vector Y from subroutine YRAE and Range.

Calculate residuals in $\overrightarrow{UP}$, $\overrightarrow{DOWN}$, $\overrightarrow{CROSS}$.

$$\Delta UP = (\vec{Y} - \vec{W}) \cdot \overrightarrow{UP}$$

$$\Delta DOWN = (\vec{Y} - \vec{W}) \cdot \overrightarrow{DOWN}$$

$$\Delta CROSS = (\vec{Y} - \vec{W}) \cdot \overrightarrow{CROSS}$$

Vector magnitude (VM)

$$VM = |\vec{Y} - \vec{W}|$$

and

$$\beta = \sin^{-1} \left[\frac{\overrightarrow{CROSS} \cdot \vec{Y}}{|Y|} \right]$$

SUBROUTINE IDENTIFICATION

A. Title

PARSET

B. Segment

MHESPOD

C. Called by subroutine

MESPOD

FUNCTION

This subroutine sets up the PSTAT array with sensor information from the master sensor table for a given sensor number.

USAGE

A. Calling sequence

Call PARSET

B. Input

1. COMMON

NSTAT	Identifies the starting location of the master sensor table
PLSTSN	Name of the last sensor processed by RADR
PUBS	Current observations and time table
VSTR	Floating point variable storage

2. Calling sequence

—

C. Output

1. COMMON

PSTAT	(1)	ϕ_s	sensor latitude (rad)
	(2)	λ_s	sensor longitude (rad)
	(3)	h	sensor altitude (e.r.)

(4) $\cos \phi_s$

(5) $\sin \phi_s$

(6) $\alpha_{go} + \lambda_s$

(7) ω_1^s }

(8) ω_3^s } coordinates this sensor in the W system (e.r.)

(9) Code word (see definition of IVSTR(NPRCD) array)

TG Observation time (adjusted by approximate time bias if applicable).

2. Calling sequence

—

D. Error/action messages

"STATION NOT IN MASTER SENSOR TABLE"

After this message is printed control is returned to the main sequence and the next observation time is selected.

SUBROUTINES USED

A. Library

—

B. Program

MATCH

EQUATIONS

—

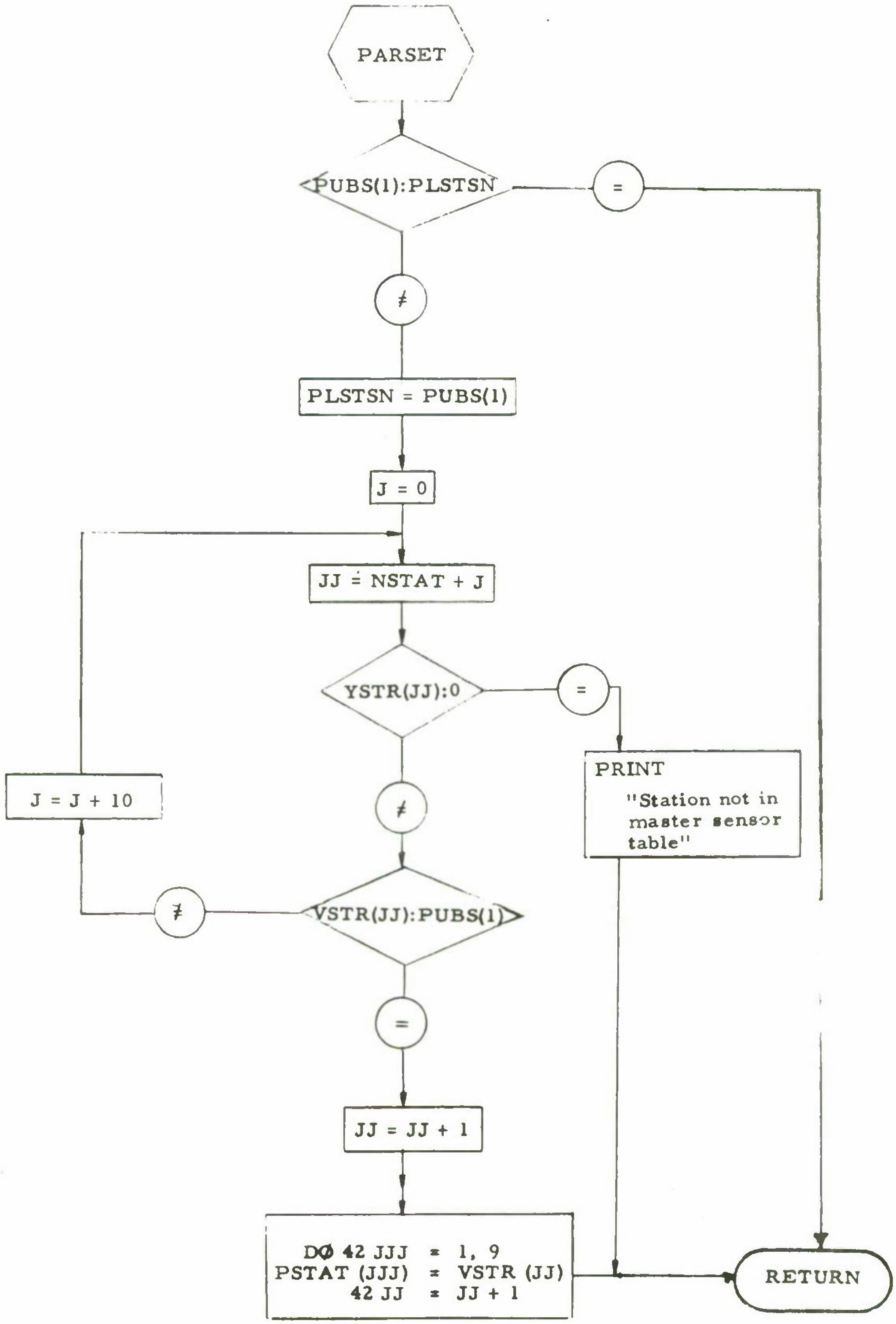


Figure 5-30. PARSET Flow Diagram

SUBROUTINE IDENTIFICATION

A. Title

PARSET

B. Segment

NRTPOD

C. Called by subroutine

DCITER
TRJGEN

FUNCTION

This subroutine sets up the PSTAT array with sensor information from the master sensor table for a given sensor number. It checks to see if either latitude, longitude, altitude, or time biases are being solved for by this sensor and if so, updates the PSTAT table before returning to the main sequence.

USAGE

A. Calling sequence

Call PARSET (NOSEN)

B. Input

1. COMMON

CBE	b_e (1.0 - Ellipticity of earth)
CDEG	degrees/radian
KOUT	Symbolic output tape
NPBIS	Identifies table for definition of Category 2 variables
NPRCD	Identifies table for definition of Category 2 variables to be solved for
NSTAT	Identifies the starting location of the master sensor table
PLSTSN	Name of the last sensor processed by RADR
PUBS	Current observations and time array
TG	Time to integrate to (min)
TMBIS	Current estimate of time bias for the observation time being considered
VSTR (NSTAT)	Variable storage - master sensor table.

2. Calling sequence

—

C. Output

1. COMMON

PSTAT(1) ϕ_s sensor latitude (rad)

(2) λ_s sensor longitude (rad)

(3) h sensor altitude (e.r.)

(4) $\cos \phi_s$

(5) $\sin \phi_s$

(6) $x_{go} + \lambda_s$

(7) W_1^s

(8) W_3^s

(7)–(8): coordinates of this sensor in the W system (e.r.)

(9) Code word (see definition of IVSTR (NPRCD) array in ESPOD Mathematical and Subroutine Description)

TG Observation time (adjusted by approximate time bias if applicable)

2. Calling sequence

NOSEN Flag to indicate a sensor not found in the master sensor list.

NOSEN = 0, sensor found in master sensor list.
NOSEN = 1, sensor not found in master sensor list.

D. Error/Action Message

"STATION XX NOT IN MASTER SENSOR LIST"

After this message is printed, control is returned to the main sequence and the next observation time is selected.

SUBROUTINES USED

A. Library

COS
SIN
SQRT

B. Program

MATCH

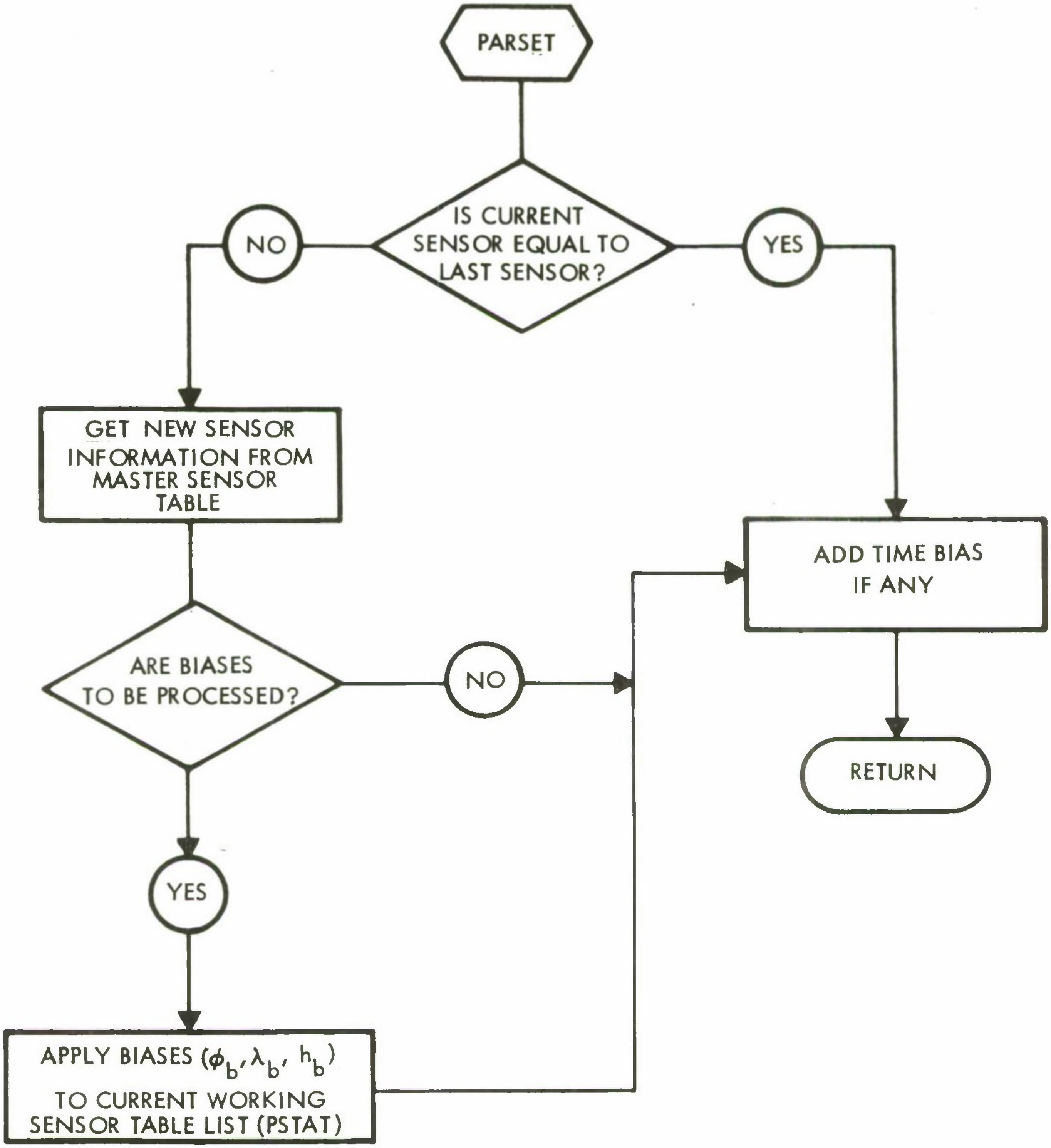


Figure 5-31. PARSET Flow Diagram

SUBROUTINE IDENTIFICATION

A. Title

PASTOR

B. Segment

NRTPOD

C. Called by subroutine

REJECT

FUNCTION

To store into PDELFG an indicator defining the rejection of an observation in the differential correction process.

USAGE

A. Calling sequence

CALL PASTOR (PDELFG, I1, I5)

B. Input

1. COMMON

—

2. Calling sequence

I1 index on PDELFG indicating data type being tested
- I1 = 1 indicates range residual deletion
- I1 = 2 indicates azimuth residual deletion
- I1 = 3 indicates elevation residual deletion
- I1 = 4 indicates range rate residual deletion

I5 indicates to PASTOR the criteria of deletion
- I5 = 1 The observation residual is to be deleted by input DELET cards.
- I5 = 2 The observation residual has failed the K*RMS test.
- I5 = 3 The observation residual has failed the gross outlier test.
- I5 = 4 The observation residual is to be deleted due to an observation weight being zero.

C. Output

1. COMMON

—

2. Calling sequence

PDELFG (I1) Array containing in each cell either

a) Word containing "*" indicating the observation was deleted by input DELET cards.

b) Word containing "k" indicating the observation residual has failed the K*RMS test.

c) Word containing "N" indicating the observation residual has failed the gross outlier $N*\sigma$ test.

d) Word containing "S" indicating the observation was deleted due to an observation weight being zero.

D. Error/Action Messages

—

SUBROUTINES USED

A. Library

—

B. Program

—

SUBROUTINE IDENTIFICATION

A. Title

PIMOD

B. Segment

PREMOD
MJESPOD
NRTPOD

C. Called by subroutines

—

FUNCTION

Function is to get the positive argument of an angle in radians between 0 and 2π.

USAGE

A. Calling sequence

PIMOD(A)

B. Input

1. COMMON

C2PI 2π

2. Calling sequence

A Angle in radians

C. Output

1. COMMON

—

2. Calling sequence

A · Positive angle between 0 and 2π in radians

SUBROUTINES USED

A. Library

AMOD

B. Program

—

SUBROUTINE IDENTIFICATION

A. Title

POTENT

B. Segment

MHESPOD
PREMOD
NRTPOD

C. Called by subroutines

DAUX

FUNCTION

Function is to compute the necessary inputs for and to call the GPERT subroutine.

USAGE

A. Calling sequence

Call POTENT

B. Input

1. COMMON

TLIST	Numerical integration working storage
TR	Magnitude of vector from center of earth to vehicle
TALFAG	Right ascension of Greenwich meridian at mid-night day of epoch
CWE	Earth's rotation rate (radians/minute)

2. Calling sequence

—

C. Output

1. COMMON

SIPH	sin of the geocentric latitude of the vehicle
COPH	cos of the geocentric latitude of the vehicle
SNALF	sin of the right ascension of the vehicle
CSALF	cos of the right ascension of the vehicle
SILA	sin of the longitude of the vehicle
COLA	cos of the longitude of the vehicle

2. Calling sequence

—

POTENT

SUBROUTINES USED

A. Library
   COS
   SIN
   SQRT

B. Program
   GPERT
   PIMOD

EQUATIONS

$$\cos\phi = \frac{\sqrt{x^2 + y^2}}{R} \qquad \sin\phi = \frac{z}{R}$$

$$\cos a = \frac{x}{\sqrt{x^2 + y^2}} \qquad \sin a = \frac{y}{\sqrt{x^2 + y^2}}$$

$$\lambda = a - (a_{go} + \omega_e t)$$

$$\cos\lambda = \cos a \cos(a_{go} + \omega_e t) + \sin a \sin(a_{go} + \omega_e t)$$

$$\sin\lambda = \sin a \cos(a_{go} + \omega_e t) - \cos a \sin(a_{go} + \omega_e t)$$

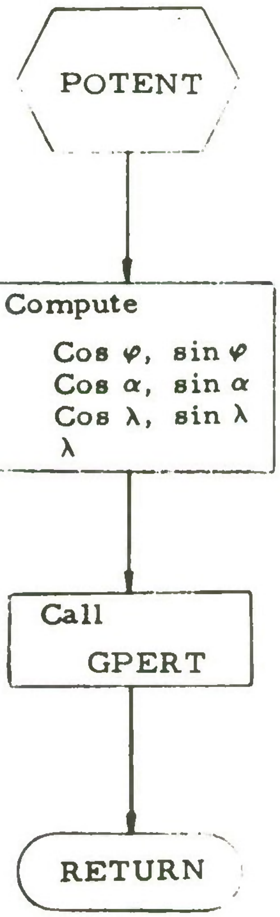


Figure 5-32. POTENT Flow Diagram

SUBROUTINE IDENTIFICATION

A. Title

PRAUPD

B. Segment

NRTPOD

C. Called by subroutine

PRUDRV

FUNCTION

Function is to update a given covariance matrix to a specified time t, and to print the resulting matrices. The covariance matrix to be updated can either be a 6 x 6 (α, δ, β, A, R, v) or a 7 x 7 (α, δ, β, A, R, v, $C_DA/2m$). The updated normal matrix (polar spherical coordinates) and a correlation matrix is printed.

USAGE

A. Calling sequence

CALL PRAUPD

B. Input

1. COMMON

KOUT	Symbolic output tape (print)
NPR	Number of all parameters to solve for
NDPR	Number of category 1 parameters to solve for
NATA	Starting location of where the triangular A^TA is stored (VSTR(NATA))
NR	Starting location of where the inverse A^TA is stored (VSTR(NR))
NSCALE	Starting location of the list of conversion factors which convert from machine to output units and vice versa
NDPAR1	Starting location where the solution vector will be stored
NRTMP	Starting location of temporary storage for special handling of the R matrix
NBDNS	Starting location for the bounds used by LEGS
TEMP	Temporary storage
VSTR	Variable storage. VSTR (NR), VSTR (NRTMP), VSTR (NBDNS) etc
TRAJX	Contains the position, velocity and acceleration vectors of the vehicle

	The variational equations may also be present in TRAJX
TZ	Indicates if the solution was affected by bounds

2. Calling sequence

—

C. Output

Off-line print

Sigma and Rho matrix (polar spherical coordinates)

Normal matrix (polar spherical coordinates)

D. Error/action messages

SUBROUTINES USED

A. Library

—

B. Program

MATPT

HUMAH
PPLPC
CORMAT
MABAT
LEGS 2

SUBROUTINE IDENTIFICATION

A. Title

PRCONS

B. Segment

NRTPOD - Input Processor

C. Called by subroutine

INPUT

FUNCTION

The functions are to print the program constants, input parameters, variable storage pointers, lunar-solar position ephemerides, if input, and the working storage cells of blank COMMON. Along with each quantity of off-line print is an index showing the relative location of that item within the block array.

USAGE

A. Calling sequence

CALL PRCONS

B. Input

1. Blank COMMON

KOUT	Symbolic output tape number
NDAYS	NAMELIST input parameter denoting the number of days of lunar solar ephemeris input data

2. Labeled COMMON

/VSTR/

VSTR	Variable storage array

/EPHCOM/

ECOM	Ephemeris array of positions of the sun and moon and the corresponding 2nd and 4th differences

/INPP/

DATA	Temporary storage used by the input processor link. DATA acts mainly as a buffer for input data arrays

3. Calling sequence

—

C. Output

1. COMMON

—

2. Calling sequence

—

D. Error/action messages

SUBROUTINES USED

A. Library

—

B. Program

—

SUBROUTINE IDENTIFICATION

A. Title

PRECES

B. Program

PREMOD

C. Called by subroutines

PREMOD

FUNCTION

To precess the lunar polar ephemeris data from the mean equator and equinox of 1950.0 to the true equator and equinox of 0 hours, day of epoch.

USAGE

A. Calling sequence

Call PRECES

B. Input

1. COMMON

PPOS — A 24-cell vector containing the position of the moon and sun for the 4 days of the ephemeris. The order is

$x_{m_1}, y_{m_1}, z_{m_1}, x_{s_1}, y_{s_1}, ---, z_{s_4}$ Units of each radii. Mean of 1950.

PDEL2 — A 24-cell vector containing the second central differences for the ephemeris of the moon and sun for the 4 days of interest. The order is $\delta^2 x_{m_1}, \delta^2 y_{m_1}, \delta^2 z_{m_1}, \delta^2 x_{s_1}, \delta^2 y_{s_1}, \ldots, \delta^2 z_{s_4}$

PDEL4 — A 24-cell vector containing the fourth central differences for the ephemeris of the moon and sun for the 4 days of interest. The order is $\delta^4 x_{m_1}, \delta^4 y_{m_1}, \delta^4 z_{m_1}, \delta^4 x_{s_1}, \delta^4 y_{s_1}, \ldots, \delta^4 z_{s_4}$

COMMON

TJDATE	Julian Date of 0 hours day of epoch.
XJD	4-cell vector containing the Julian Date — 2430000.0 at 0 hours of each day of ephemeris.
KOUT	Logical number of printed output device.

2. Calling sequence

None

C. Output

1. COMMON

POS(4, 3, 2)	The position of the moon and sun in true of 0 hours day of epoch. Subscript 1 defines the 4 days of data, subscript 2 defines the x, y, z coordinates, and subscript 3 defines the moon and sun.
DEL2(4, 3, 2)	The second differences for the moon and sun ephemeris as defined in POS.
DEL4(4, 3, 2)	The fourth differences for the moon and sun ephemeris as defined in POS.

2. Calling sequence

None

D. Error/action messages

If the epoch date does not fall within the first and last days of the ephemeris data the following message is printed:

****SUN-MOON EPHEMERIS DOES NOT BOUND EPOCH.

and the run is terminated.

SUBROUTINES USED

A. Library

.FVIO.	EXIT	.FFIL.
.FPRN.	.FWRD.	

B. Program

ROTRU	Rotates a 3-dimensional vector from mean of 1950 to true of an arbitrary date

EQUATIONS

None

SUBROUTINE IDENTIFICATION

A. Title

PRECES

B. Segment

NRTPOD - Input processor

C. Called by subroutine

INPUT

FUNCTION

To precess the lunar-solar ephemeris input data from the mean equator and equinox of 1950. 0 to the true equator and equinox of 0 hours day of epoch.

USAGE

A. Calling sequence

CALL PRECES

B. Input

1. Blank COMMON

TJDATE	Julian date of 0 hours, day of epoch
NDAYS	NAMELIST input parameter denoting the number of days of lunar solar ephemeris input data
KOUT	Symbolic output tape (print)

2. Labeled COMMON

/TEMP/

TEMP	Temporary storage

/INPP/

TPOS A 60-cell vector containing the position of the moon and sun for NDAYS days. TPOS array order is

$x_{a_1}, y_{a_1}, z_{a_1}, x_{\odot_1}, y_{\odot_1}, z_{\odot_1}, x_{a_2},$ *

$y_{a_2}, z_{a_2}, \ldots\ldots\ldots, x_{a_{NDAYS}},$

$y_{a_{NDAYS}}, z_{a_{NDAYS}}, x_{\odot_{NDAYS}},$

$y_{\odot_{NDAYS}}, z_{\odot_{NDAYS}}$

Units of earth radii - Mean of 1950.

TDEL2 A 60-cell vector containing the second central differences of the position ephemeris of the moon and sun for NDAYS days. TDEL2 array order is

$\delta^2 x_{a_1}, \delta^2 y_{a_1}, \delta^2 z_{a_1}, \delta^2 x_{\odot_1}, \delta^2 y_{\odot_1},$

$\delta^2 z_{\odot_1}, \ldots\ldots, \delta^2 x_{a_{NDAYS}}, \delta^2 y_{a_{NDAYS}},$

$\delta^2 z_{a_{NDAYS}}, \delta^2 x_{\odot_{NDAYS}}, \delta^2 y_{\odot_{NDAYS}},$

$\delta^2 z_{\odot_{NDAYS}}$

Units of earth radii - Mean of 1950.

TDEL4 A 60-cell vector containing the fourth central differences of the position ephemeris of the moon and sun for NDAYS days. TDEL4 array order is

$\delta^4 x_{a_1}, \delta^4 y_{a_1}, \delta^4 z_{a_1}, \delta^4 x_{\odot_1}, \delta^4 y_{\odot_1}, \ldots$

$\ldots, \delta^4 z_{a_{NDAYS}}, \delta^4 x_{\odot_{NDAYS}},$

$\delta^4 y_{\odot_{NDAYS}}, \delta^4 z_{\odot_{NDAYS}},$

Units of earth radii - Mean of 1950

---

* a - moon
$\odot$ - sun

3. Calling sequence

—

C. Output

1. Blank COMMON

—

2. Labeled COMMON

/EPHCOM/

POS(10, 3, 2)	The positions of the moon and sun. The first subscript defines the days of data, the second subscript defines the x, y, z coordinates, and subscript 3 defines the moon and sun. Units of earth radii – true of 0 hours, day of epoch.
DEL2(10, 3, 2)	The second central differences for the lunar-solar ephemeris as defined in POS.
DEL4(10, 3, 2)	The fourth central differences for the lunar-solar ephemeris as defined in POS.

3. Calling sequence

—

D. Error/action messages

1. Off-line comment

"****SUN-MOON EPHEMERIS DOES NOT BOUND EPOCH"

2. On-line comment

—

3. If the epoch date does not fall within the first and last days of the lunar-solar ephemeris data, the off-line comment mentioned above is printed and the run is terminated with a

CALL EXIT.

SUBROUTINES USED

A. Library

—

B. Program

ROTRU	Rotates a 3-dimensional vector from mean of 1950 to true of an arbitrary data

SUBROUTINE IDENTIFICATION

A. Title
PRELIM

B. Segment
MHESPOD
PREMOD
NRTPOD

C. Called by subroutine
RADR

FUNCTION

The function is to calculate preliminary quantities for the formulation of residuals and partial derivatives of observation with respect to solution parameters.

USAGE

A. Calling sequence

Call PRELIM

B. Input

1. COMMON

a.	PSTAT(4)	Cos ϕ^*
	PSTAT(5)	Sin ϕ^*
	PSTAT(6)	$\alpha_{g_0} + \lambda$ (rad)
	PSTAT(7)	w_1^s (e. r.)
	PSTAT(8)	w_3^s (e. r.)
b.	PUBS(1)	T (min)
	PUBS(6)	$\dot{R}$ (e. r. /min)
c.	TRAJ(1)	x
	TRAJ(2)	y
	TRAJ(3)	z
	TRAJ(4)	$\dot{x}$
	TRAJ(5)	$\dot{y}$
	TRAJ(6)	$\dot{z}$
	TRAJ(10)	> TRAJX(57) = partials of TRAJ(1-6) with respect to Pi, i = 1, NDPR
d.	NDPR	Number of all differential plus initial parameters to solve for (Category 1)
e.	TEMP	Temporary storage
f.	CWE	Earth's rotational rate

2. Calling sequence

—

C. Output

1. COMMON

a.	PCMR	R = computed slant range
b.	PCSA	Cos A_c
c.	PCSALF	Cos (α [illegible])
d.	PCSE	Cos E [illegible]
e.	PRSUB1	R_1 = [illegible]
f.	PSNA	Sin A [illegible]
g.	PSNALF	Sin (α [illegible]
h.	PSNE	Sin E [illegible]
i.	PUDTI	Vector $(\dot{u}_1, \dot{u}_2, \dot{u}_3)$
j.	PUI	Vector (u_1, u_2, u_3)
k.	PV	$\sqrt{v_1^2 - v_2^2}$
l.	PVI	Vector (v_1, v_2, v_3)
m.	PWDTI	Vector $(\dot{w}_1, \dot{w}_2, \dot{w}_3)$
n.	PWDTPP	Partial derivatives
o.	PWI	Vector (w_1, w_2, w_3)
p.	PWPP	Partial derivatives

2. Calling sequence

—

D. Error/action messages

—

SUBROUTINES USED

A. Library

COS
SIN
SQRT

B. Program

—

EQUATIONS

The computed orbit positions (x, y, z) and station positions (ϕ^*, λ, h) are processed to produce geocentric and topcentric coordinates of the vehicle in an Earth-fixed coordinate system. Right ascensions of the station for times of observations t_i are

$$\alpha_i = (\alpha_{go} + \lambda) + \omega_e (t_i - t_o)$$

Geocentr c position and velocity of the vehicle in **Earth-fixed** coordinates are

$$\begin{bmatrix} w_1 \\ w_2 \\ w_3 \end{bmatrix}_i = \begin{bmatrix} \cos \alpha_i & \sin \alpha_i & 0 \\ -\sin \alpha_i & \cos \alpha_i & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

$$\begin{bmatrix} \dot{w}_1 \\ \dot{w}_2 \\ \dot{w}_3 \end{bmatrix}_i \quad \begin{bmatrix} \cos \alpha & \sin \alpha & 0 \\ -\sin \alpha & \cos \alpha & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \dot{x} + \omega_e y \\ \dot{y} - \omega_e x \\ \dot{z} \end{bmatrix}$$

The station position in meridian coordinates is provided by the preprocessor module where it is computed from geodetic latitude, ϕ^*, and altitude, h, as follows.

$$A_s = \left(\cos^2 \phi^* + b_e^2 \sin^2 \phi^* \right)^{-1/2}$$

$$B_s = \left(\sin^2 \phi^* + \frac{1}{b_e^2} \cos^2 \phi^* \right)^{-1/2}$$

$$w_1^s = (A_s + h) \cos \phi^*$$

$$w_3^s = (b_e B_s + h) \sin \phi^*$$

where b_e is the polar axis of the reference spheroid.

Topocentric coordinates, direction consines, and related quantities for the vehicle in meridian plane coordinate system are then

$q_1 = w_1 - w_1^s$ (Topocentric position in equatorial coordinate system)

$q_2 = w_2$

$$q_3 = w_3 - w_3^s$$

$$R = \sqrt{q_1^2 + q_2^2 + q_3^2}$$

$$\bar{u} = \begin{cases} u_1 = q_1/r \\ u_2 = q_2/r \\ u_3 = q_3/r \end{cases}$$

(Topocentric direction cosines in equatorial system)

$$\dot{\bar{u}} = \begin{cases} \dot{u}_1 = (\dot{w}_1 - K\, u_1)/r \\ \dot{u}_2 = (\dot{w}_2 - K\, u_2)/r \\ \dot{u}_3 = (\dot{w}_3 - K\, u_3)/r \end{cases}$$

$$K = u_1\, \dot{w}_1 + u_2\, \dot{w}_2 + u_3\, \dot{w}_3$$

$$\bar{v} = \begin{cases} v_1 = u_2 \\ v_2 = -u_1 \sin \phi^* + u_3 \cos \phi^* \\ v_3 = u_1 \cos \phi^* + u_3 \sin \phi^* \end{cases}$$

(Topocentric direction cosines in horizon system)

$$V = \sqrt{v_1^2 + v_2^2}$$

$$R_1 = VR$$

$$\sin E = v_3$$

$$\cos E = V$$

$$\cos A = v_2/V$$

$$\sin A = v_1/V$$

$$
\begin{bmatrix} \frac{\partial w_1}{\partial p_i} \\ \\ \frac{\partial w_2}{\partial p_i} \\ \\ \frac{\partial w_3}{\partial p_i} \end{bmatrix} = \begin{bmatrix} \cos a & \sin a & 0 \\ \\ -\sin a & \cos a & 0 \\ \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \frac{\partial x}{\partial p_i} \\ \\ \frac{\partial y}{\partial p_i} \\ \\ \frac{\partial z}{\partial p_i} \end{bmatrix}
$$

If range rate observations are used (PUBS $\neq$ 0), then variational equations in velocity are rotated as follows.

$$
\begin{bmatrix} \frac{\partial \dot{w}_1}{\partial p_i} \\ \\ \frac{\partial \dot{w}_2}{\partial p_i} \\ \\ \frac{\partial \dot{w}_3}{\partial p_i} \end{bmatrix} = \begin{bmatrix} \cos a & \sin a & 0 \\ \\ -\sin a & \cos a & 0 \\ \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \frac{\partial \dot{x}}{\partial p_i} + \omega_e \frac{\partial y}{\partial p_i} \\ \\ \frac{\partial \dot{y}}{\partial p_i} - \omega_e \frac{\partial x}{\partial p_i} \\ \\ \frac{\partial \dot{z}}{\partial p_i} \end{bmatrix}
$$

where the parameters p_i are the ADBARV conditions at epoch (a_o, δ_o, β_o, A_o, r_o, v_o), drag parameter ($C_D A/2m$) and coefficient of diurnal drag variation, ϵ.

SUBROUTINE IDENTIFICATION

A. Title

PREMOD (Main Control)

FUNCTION

The main control subroutine for the MHESPOD – DAP preprocessor module. This subroutine also controls the printing of the ADT and DAP tapes. (See flow chart.)

USAGE

A. Calling sequence

—

B. Input

—

C. Output

The subroutine generates MCOM, DAPRE, the core ephemeris, and the pre-epoch observation records on the BCT.

D. Error/action messages

The card images of the JDC and comments cards are printed by PREMOD. The message:

FINAL INITIAL CONDITIONS AT TNULL or TRISE

is printed by PREMOD.

SUBROUTINES USED

A. Library

.FWRT.	.FRDD.	.FFIL.	.FBLT.
.FVIO.	.FWRB.	.FCNV.	.FWLR.
.FEFT.	.FWRD.	.FRTN.	

B. Program

DAPRT	Prints the DAP raw-averaged data tape
TRISE	Determines time of rise at Millstone Hill
SETCON	Presets MCOM and PCOM constants
RDCOM	Reads MCOM from the ADT
TRAJ	Performs numerical integration of equation of motion and variational equations

TINIT	Computes epoch time and right ascension of Greenwich at 0 hours epoch day
TSET	Determines time of set at Millstone Hill
IPRNT	Prints epoch time and Cartesian and polar initial conditions
PRECES	Precesses the ephemeris data from mean of 1950 to true of 0 hours epoch day
GENCE	Generates core ephemeris
PRTADT	Prints the ADT
LODOBS	Main control for observation card processing
UPDATE	Updates a priori normal matrix (ATA)
COMSET	Resets MCOM before BCT is written
LODSEN	Main control for sensor card processing
SETSTR	Sets selected cells in MCOM and PCOM based on the NAMELIST input
WRTCOM	Writes MCOM record on the BCT
SETIC	Initializes integration list
DAPOB	Processes DAP obs from ADT
RDDATA	Reads NAMELIST, mean elements and ephemeris cards
DPRLM	Computes initial conditions in Cartesian coordinates

SUBROUTINE IDENTIFICATION

A. Title

PRTADT

B. Segment

PREMOD

C. Called by subroutine

PREMOD

FUNCTION

To format and print the ADT, the after-differential correction tape output by MHESPOD. The new initial conditions on each iteration are converted to SPADATS mean orbital elements and output.

USAGE

A. Calling sequence

CALL PRTADT

B. Input

1. COMMON

KOUT	The logical number of the printed output device
KADT	The logical number of the ADT tape
CKMER	Kilometers for earth radius
CDEG	Degrees per radian
CKMFT	Kilometers per foot
NSCALE	Location in VSTR of the first cell of the scale vector for the solution vector
VSTR	Block of storage containing arrays and vectors associated with the MHESPOD solution vector
NPR	Number of parameters in the solution vector
IPADT	Flag to indicate whether the core ephemeris is to be printed from the ADT if IPADT = 0, 1 ... do not print core ephemeris = 2 ... do print core ephemeris

2. Calling sequence

—

C. Output

1. COMMON

NDAPOB	Number of DAP observations on the ADT

2. Calling sequence

—

D. Error/action messages

If the first word of the first record of the ADT is not ADTbbb in BCD, the following message is printed.

*****TAPE ID IS NOT ADT

and the job is terminated.

E. Internal storage

FIRST	Is 0 upon entrance to the routine and set $\neq$ 0 when the residuals print header is output the first time. This flag is used to eject the page before printing the residuals starting with iteration 2.
HEAD	A 12-cell block to contain words 3-14 of the ADT ID record. These words were obtained from the REMARK card used when generating the BCT for the MHESPOD run.
TAPID	Word 1 of the ADT ID record, should be ADTbbb
IDTRG	Target ID from word 2 of the ADT ID record.
SIGMA	The standard deviation of parameter i in the solution vector in external units. i varies from 1 to 6 corresponding to x, y, z, $\dot{x}$, $\dot{y}$, $\dot{z}$.
BUFF	A 70-cell block into which the residual and iteration summary records of the ADT are read.

SUBROUTINES USED

A. Library

SQRT
EXIT

B. Program

MATPT	Prints a lower triangular matrix stored by rows
CTOM	Converts osculating Cartesian elements to mean
HUMAH	Scales a vector, ATA matrix and $(A^TA)^{-1}$ matrix from internal to external units and vice-versa
DOBPRT	Prints the DAP observations on the ADT

EQUATIONS

The σ_i is computed from the diagonal elements of the $(A^TA)^{-1}$ variance covariance matrix.

$$(A^T A)^{-1} = \begin{bmatrix} \sigma_{11}^{2} & & & \\ \sigma_{12} & \sigma_{22}^{2} & & \\ \vdots & & \ddots & \\ \sigma_{16} & \cdots & \cdots & \sigma_{66}^{2} \end{bmatrix}$$

PRTADT

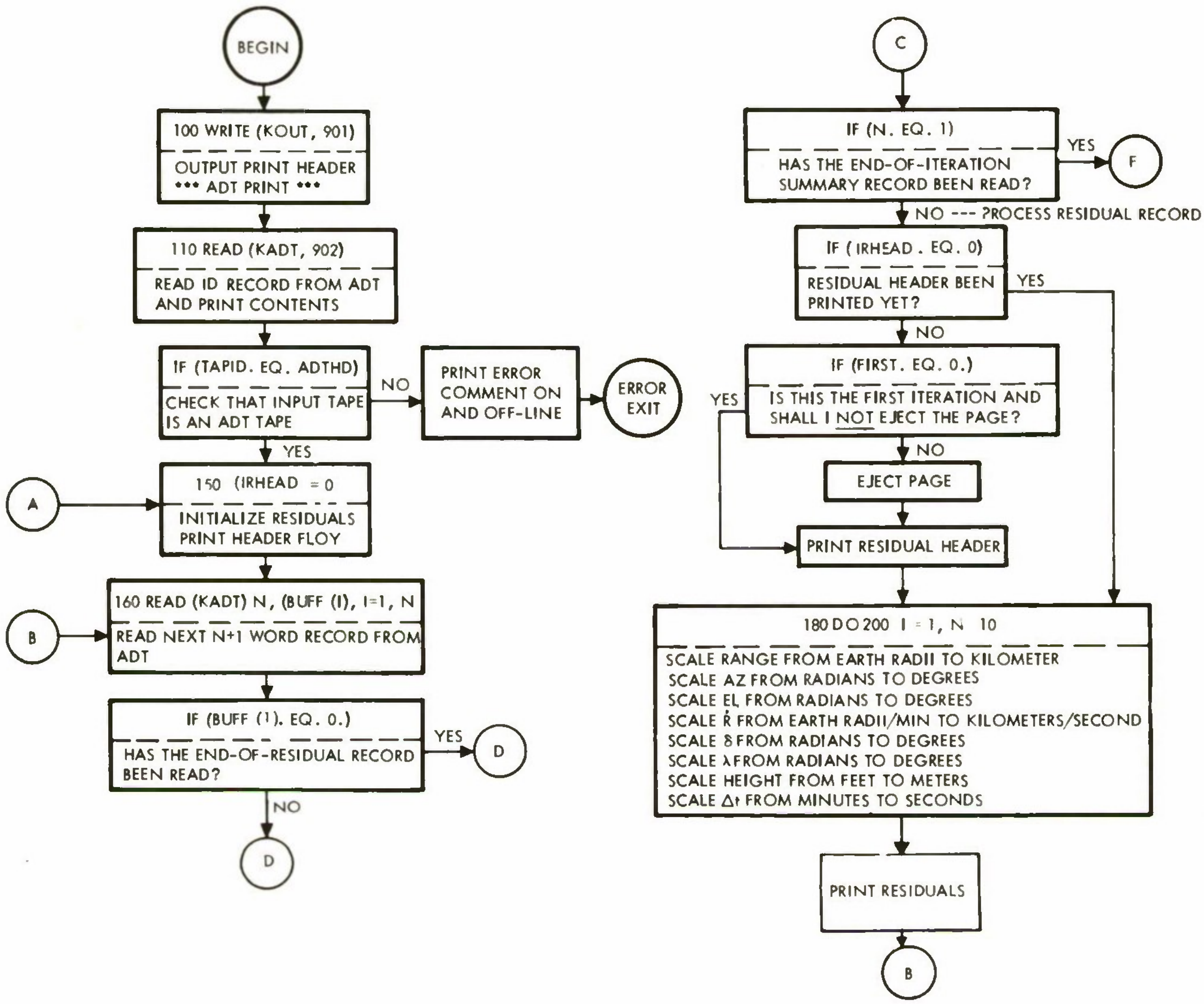


Figure 5-33. PRTADT Flow Diagram

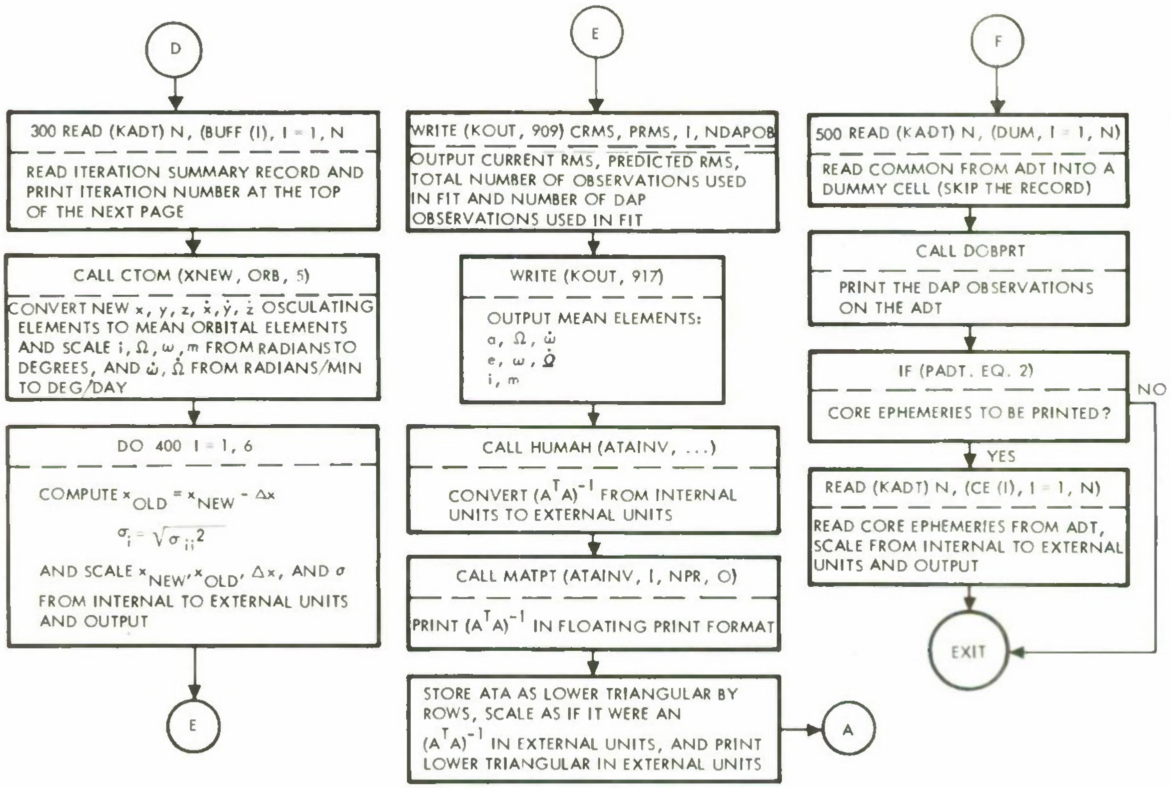


Figure 5-33. PRTADT Flow Diagram (Continued)

SUBROUTINE IDENTIFICATION

A. Title

PRTATA

B. Segment

NRTPOD

C. Called by subroutine

APPLY

FUNCTION

The functions are to move the de-augmented $A^T A$ and store by rows as a lower triangular matrix in VSTR(NRTMP), to scale as an input $A^T A$ inverse, and to print the $A^T A$ by MATPT.

USAGE

A. Calling sequence

CALL PRTATA

B. Input

1. COMMON

NPR	Total number of parameters to solve for
NATA	Starting location of where the triangular $A^T A$ is stored
NRTMP	Starting location of temporary storage for special handling of the R matrix
NSCALE	Starting location of list of conversion factors which convert from machine to output units and vice-versa
KOUT	Symbolic output tape

2. Calling sequence

—

C. Output

1. COMMON

VSTR (NRTMP)	Contains the scaled A^TA normal matrix which is output off-line

2. Calling sequence

—

D. Error/action messages

SUBROUTINES USED

A. Library

—

B. Program

HUMAH

MATPT

SUBROUTINE IDENTIFICATION

A. Title

PRUDRV

B. Segment

NRTPOD

C. Called by Subroutine

TRJPRO

FUNCTION

Function is to control the post-processing capability of NRTPOD. The trajectory propagation and covariance matrix update is performed in this post-processing link.

USAGE

A. Calling Sequence

Call PRUDRV

B. Input

1. COMMON

ITRJTP	Trajectory tape
TRAJX	Array containing position, velocity, accelerations and partials of position, velocity with respect to CAT1 variables
PSTFLG	Columns 51-60 on JDC card
TEMP	Array of temporary storage

2. Calling Sequence

—

C. Output

1. COMMON

TG	Time to integrate to (min)
TCRASH	Impact flag

2. Calling Sequence

—

D. Error/Action Messages

—

SUBROUTINES USED

A. Library

—

B. Program

TPRNT	Routine to print trajectory block
PRAUPD	Prints and updates covariance and correlation matrices

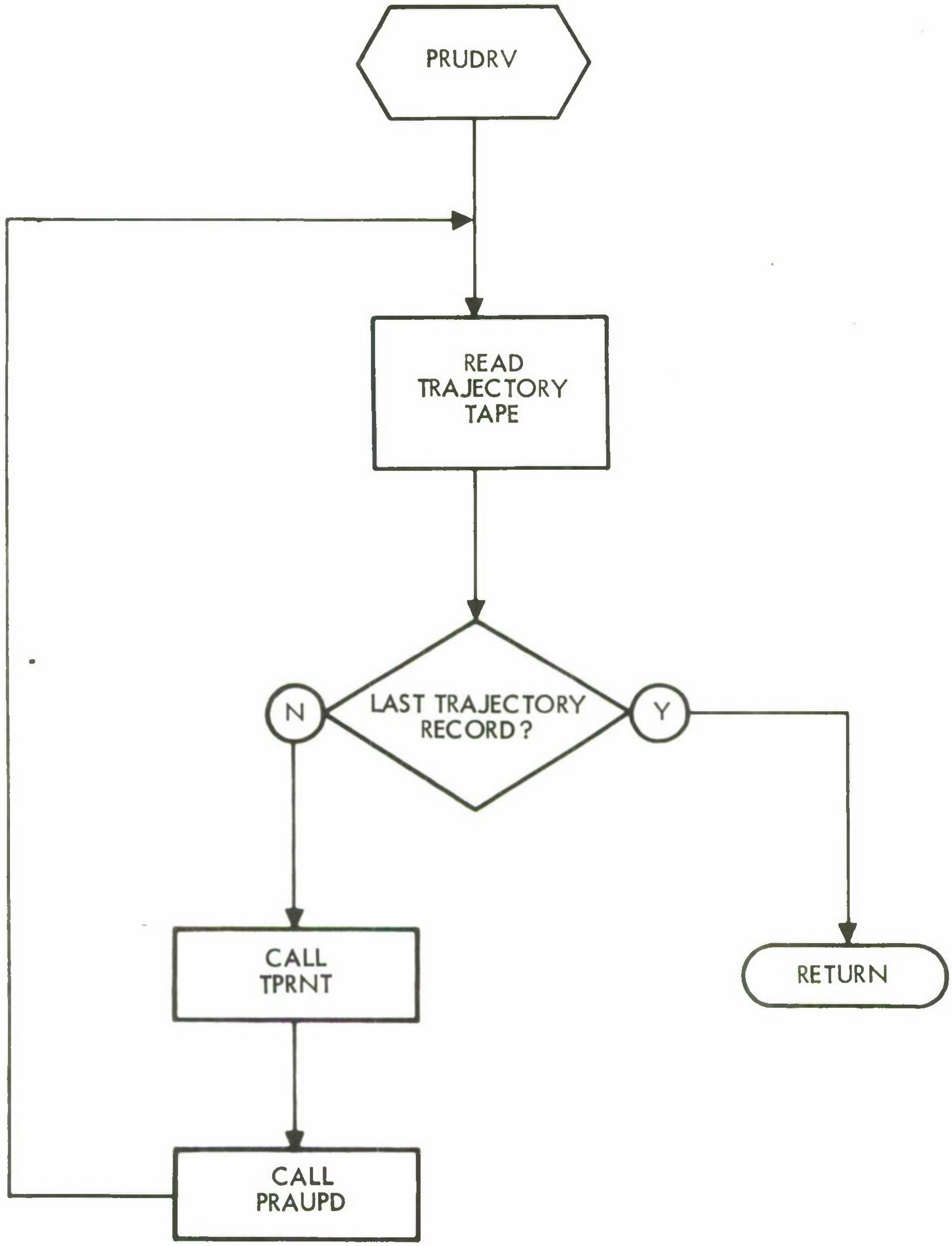


Figure 5-34. PRUDRV Flow Diagram

SUBROUTINE IDENTIFICATION

A. Title

RADR

B. Segment

MHESPOD
NRTPOD

C. Called by subroutine

INTEG

FUNCTION

Function is to control region for the formulation of the system of equations to be solved (Ax = B). A is the matrix of partial derivatives of observations with respect to solution variables and B is the vector of observation residuals. RADR also drives those routines which, given A, B, form A^TA, A^TB, and B^TB. It also drives the residuals print routines.

USAGE

A. Calling sequence

Call RADR

B. Input

1. CØMMØN

IPFRST	0 to indicate first time in RADR
NARØW	Starting location where one row of the augmented matrix (A, B) is stored
NPR	Number of all parameters to solve for
PCMR	Computed slant range
PØBCNT	Total number of accepted observations
PRESD	Residuals
PSIG	Sigma list
PUBS	Sensor number, time, R, A E, $\dot{R}$, α, δ table
PUI	Vector (u_1, u_2, u_3)

PVI	Vector (v_1, v_2, v_3)
PWDTI	Vector ($\dot{w}_1$, $\dot{w}_2$, $\dot{w}_3$)
TSUS	Current total SØS
VSTR	Floating point variable storage
CPI	π
C2PI	2π
PCSE	Cos E_c

2. Calling sequence

—

C. Output

1. CØMMØN

The array VSTR (NATA) contains the total A^TA, A^TB, B^TB.

2. Calling sequence

—

D. Error/action messages

—

SUBROUTINES USED

A. Library

—

B. Program

ASIN	Arc sine routine
ATNQ	Arc tangent routine
DRDP	Partials of observations w.r.t. Category 1 variables
LEGS1	Forms A^TA and A^TB given A and B
PIMØD	Principal value of angle between 0 and 2π
PRELIM	Preliminary calculations
PAGE1	Sets residuals in buffer for ADT

EQUATIONS

Computation of Observables from Fitted Orbit

The fitted orbit is used to produce computed "observables" for comparison with observations.

$$R = \sqrt{q_1^2 + q_2^2 + q_3^2} \qquad \text{(range)}$$

$$A = \tan^{-1} v_1/v_2 \qquad \text{(azimuth)}$$

$$E = \sin^{-1} v_3 = \cos^{-1} V \qquad \text{(elevation)}$$

$$\dot{R} = \overline{u} \cdot \dot{\overline{W}} \qquad \text{(range rate)}$$

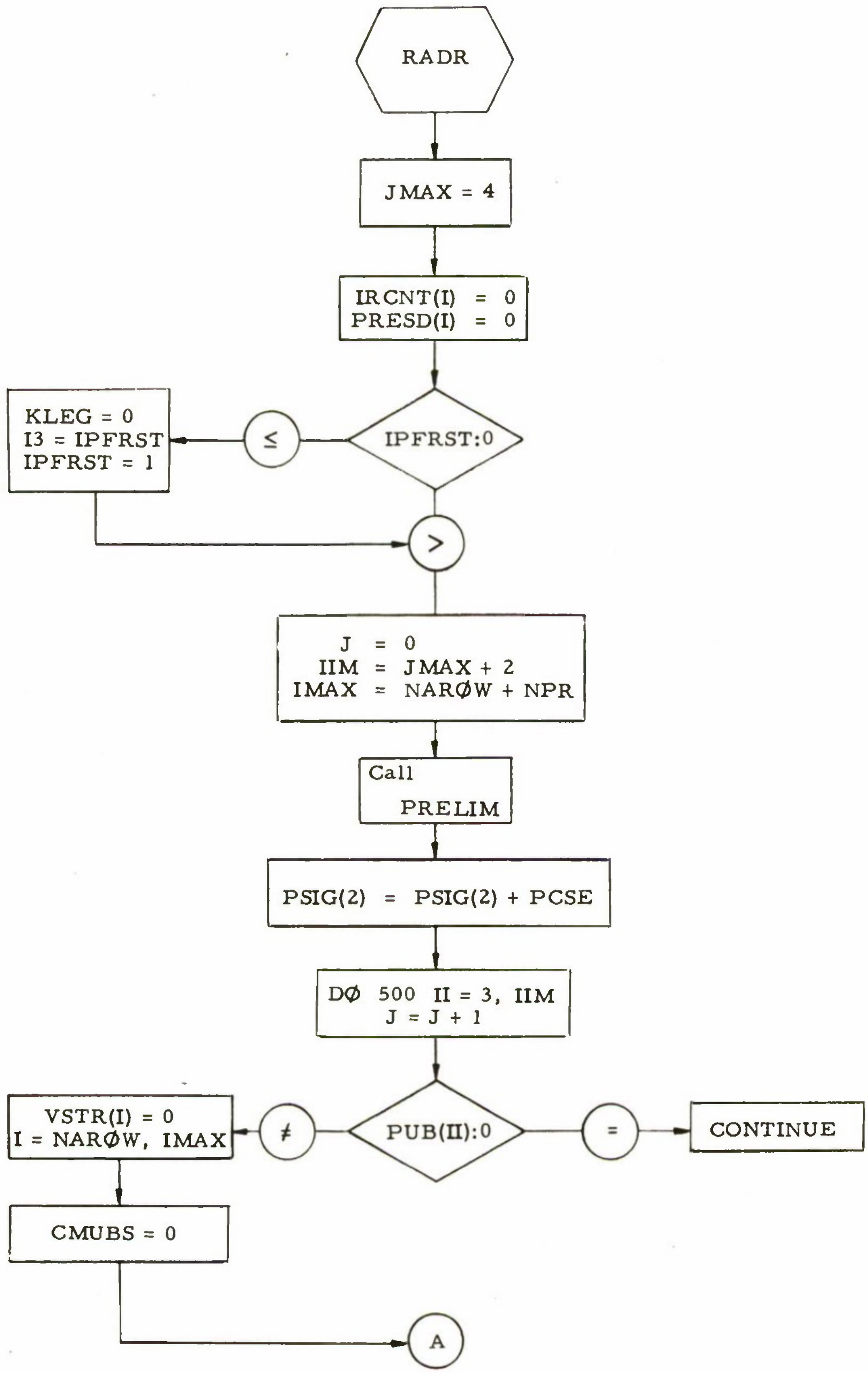


Figure 5-35. RADR Flow Diagram

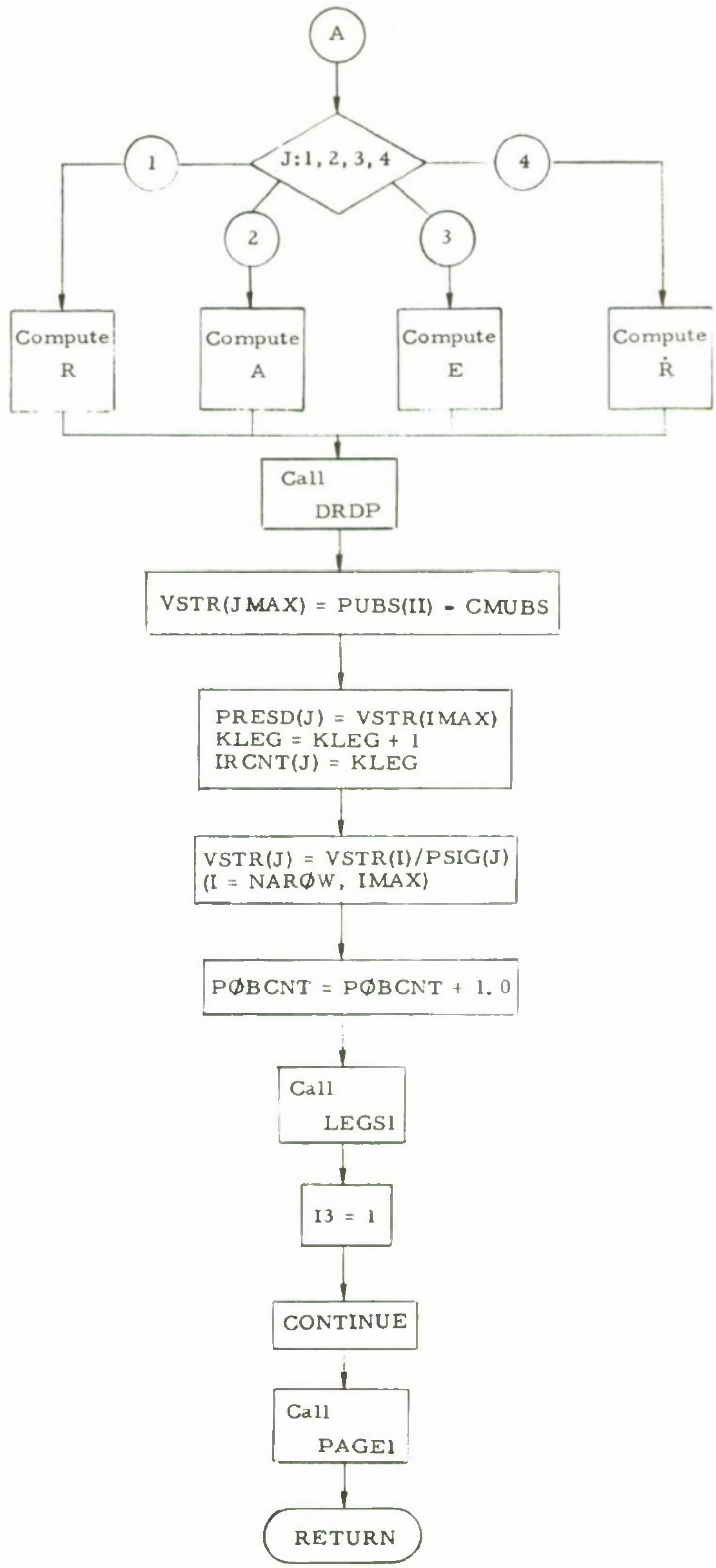


Figure 5-35. RADR Flow Diagram (Continued)

SUBROUTINE IDENTIFICATION

A. Title

RADSQ

B. Segment

MHESPOD
PREMOD
NRTPOD

C. Called by subroutines

BØDY

DAUX

DØT

RPRESS

FUNCTION

Function is to compute magnitude and magnitude squared of a given 3-D vector.

USAGE

A. Calling sequence

Call RADSQ (A(I), B, C)

B. Input

1. CØMMØN

—

2. Calling sequence

A	Name of array containing the vector
I	Subscript locating 1st component of desired vector in A

C. Output

1. CØMMØN

—

2. Calling sequence

B	Magnitude of vector
C	Magnitude squared

D. Error/action messages

—

SUBROUTINES USED

A. Library

SQRT

B. Program

—

EQUATIONS

$$C = R^2 = x^2 + y^2 + z^2$$

$$B = R = \sqrt{R^2}$$

SUBROUTINE IDENTIFICATION

A. Title

RDCOM

B. Segment

PREMOD

C. Called by subroutine

PREMOD

FUNCTION

To read the /MESCOM/ record from the ADT tape. The ADT can be positioned anywhere at the time this routine is called.

USAGE

A. Calling sequence

Call RDCOM

B. Input

1. COMMON

KADT	The logical number of the ADT

2. Calling sequence

—

C. Output

1. COMMON

MCOM	The 900-cell COMMON block from the ADT

2. Calling sequence

—

D. Error/action messages

—

E. Internal storage

DUM, IDUM	One cell used for storing the words in the ID record, residuals records, and iteration-summary records. These records are skipped.

RDCOM

SUBROUTINES USED

A. Library

—

B. Program

—

EQUATIONS

None

SUBROUTINE IDENTIFICATION

A. Title

RDDATA

B. Segment

PREMOD

C. Called by subroutine

PREMOD

FUNCTION

To read the NAMELIST input cards, the planetary ephemeris cards, and the Spadats mean elements cards.

USAGE

A. Calling sequence

Call RDDATA

B. Input

1. COMMON

KIN	Logical number of the input device	
IMESFG	MHESPOD processing flag from the IDC:	
	if = 0	Read NAMELIST input only
	if ≠ 0	Read mean elements (if necessary) and ephemeris cards

2. Calling sequence

—

C. Output

1. COMMON

DTYPE	Type of initial conditions
XJD	Julian date for each day of ephemeris data
PPOS	Position data for sun-moon ephemeris
PDEL2	Second central differences for sun-moon ephemeris
PDEL4	Fourth central differences for sun moon ephemeris
TYPE	DTYPE
STVEC	The state vector (6 coordinates)
TIME	Time at which STVEC defined in year, month, day, hour, minute, and seconds

DRAG	C_dA/m
DRAGCD	C_d for C_dA/m
DRAG	A for C_dA/m
DRAGM	m for C_dA/m
RADPR	$\gamma A/m$ for radiation pressure
RPGAM	γ for a $\gamma A/m$
RPA	A for a $\gamma A/m$
RPM	M for a $\gamma A/m$
ZONAL	Flags to indicate zonal harmonics in force model
SECT	Flags to indicate sectorial harmonics in force model
TESS	Code words describing the tesseral harmonics in the force model
NITER	Number of iterations for curve fit (maximum)
TNULL	Specification for epoch in hour, minutes, seconds from input epoch time
TB	Time at which to initiate search for rise in hours, minutes, seconds from input epoch time
TF	Maximum length of core ephemeris time interval
SMAT	a priori A^TA
RCRIT	Critical range for DAP
VCRIT	Critical range rate for DAP
STIME	Smoothing time for DAP
TBIAS	Time bias for DAP
RBIAS	Range bias for DAP
VBIAS	Doppler bias for DAP
EBIAS	Elevation bias for DAP
ABIAS	Azimuth bias for DAP
CSUBA	C_A for LAP
CSUBE	C_E for LAP
CEP1	Parameter associated with time interval of core ephemeris
SMELM	Spadats mean elements
DAYINT	Epoch day for mean elements . . . integer part
DAYFRC	Epoch day for mean elements . . . fractional part

2. Calling sequence

—

D. Error/action messages

—

E. Internal storage

—

SUBROUTINES USED

A. Library

—

B. Program

—

COMMENTS

ZONAL and Z0NAL both appear in the NAMELIST to allow for misspelling the variable name.

The mean elements are read only if DTYPE is entered as a 3. COMMES is the NAMELIST name used for referencing the /MESCOM/ block. COMPRE is the NAMELIST name used for referencing the /PRECOM/ block.

SUBROUTINE IDENTIFICATION

A. Title

RDDATA

B. Program

NRTPOD - Input processor

C. Called by subroutine

INPUT

FUNCTION

To read off-line into core storage all NAMELIST input and the lunar-solar ephemeris data

USAGE

A. Calling sequence

CALL RDDATA

B. Input

1. Blank COMMON

K1N	Symbolic input tape
KOUT	Symbolic output tape (print)
COM	Variables in BLK1 blank COMMON (See NAMELIST input and Layout of COMMON Storage sections)
DTMAX	A provision for editing residents by input (See NAMELIST input section)
NDAYS	Number of days of lunar-solar ephemeris input (See NAMELIST input section)
CNSIG	N for N (σ) deletion, a provision for editing residuals by input. (NAMELIST Input)
TIME	A 6-cell array containing epoch time in year, month, day, hour, minutes, seconds (NAMELIST Input)
DELTT	Sets of Δt (See NAMELIST Input section)

NITER	Number of iterations desired in curve fit, nominally = 1 (NAMELIST Input)
TYPE	Indicates type of initial conditions (position and velocity) input to NRTPOD (NAMELIST Input)
BFLAGS	Flags indicating whether the sun and moon are to be included in the trajectory simulation (See NAMELIST Input)
CKRMS	A provision for editing residuals by input (See NAMELIST Input section)

2. Labeled COMMON

/INPP/	
DRAG	$C_D A/m \left(\frac{\text{meter}^2}{\text{kilogram}}\right)$ (NAMELIST Input)
DRAGCD	C_D Coefficient of drag in DRAG (NAMELIST Input)
DRAGA	A - area in DRAG term (meters^2) (NAMELIST Input)
DRAGM	m - mass in DRAG term (kilogram) (NAMELIST Input)
STVEC	Array identifying the initial position and velocity. (See NAMELIST Input section)
CAT1	The CAT1 array indicates to the program the Category I variables to be solved for (See NAMELIST Input section)
CAT2	The CAT2 array indicates to the program the Category II variables to be solved for (See NAMELIST Input section)
BISES	Bias estimates: (See NAMELIST Input section)
SMAT	A priori normal matrix (See NAMELIST Input)
DELET	Input provided to edit residuals (See NAMELIST Input)
BNDS	Bounds specified to control convergence for each CAT1 or CAT2 variable selected for solution (NAMELIST Input)
ZONAL	Array of flags for callouts of the coefficients of the zonal harmonics - $J_2, \ldots, J_{12}$ (NAMELIST Input)
SECT	Array of flags for callouts of the sectorial harmonics (See NAMELIST Input Section)

TESS	Array of code words for selection of tesseral harmonics (See NAMELIST Input section)
RADPR	Radiation pressure parameter, $\frac{\gamma A}{m}$ $\left(\frac{\text{meter}^2}{\text{kilogram}}\right)$ (See NAMELIST Input)
RPGAM	Radiation pressure parameter, γ, reflectivity constant (NAMELIST Input)
RPA	Radiation pressure parameter, A, effective area of vehicle in square meters (NAMELIST Input)
RPM	Radiation pressure parameter, m, mass of the vehicle in kilograms (NAMELIST Input)
CJ	Zonal harmonics, $J_2, \ldots, J_{12}$. May be altered on input (NAMELIST Input)
CJNM	Coefficients of the sectorial and tesseral harmonics and their associated angles (See NAMELIST Input)
CLAMNN	Array containing values of the angles associated with the coefficients of the tesseral harmonics; $\lambda_2^2, \lambda_3^3, \ldots, \lambda_6^6$ (See NAMELIST Input section)
UPMAT	A priori covariance matrix (See NAMELIST Input)
TPOS	A 60-cell vector containing the position of the moon and sun for NDAYS days TPOS array order is $x_{a_1}, y_{a_1}, z_{a_1}, x_{\odot_1}, y_{\odot_1}, z_{\odot_1}, \ldots$ * $\ldots, x_{a_{NDAYS}}, y_{a_{NDAYS}}, z_{a_{NDAYS}}, x_{\odot_{NDAYS}}, y_{\odot_{NDAYS}}, z_{\odot_{NDAYS}}$ Units of earth radii - mean of 1950
TDEL2	A 60-cell vector containing the second central differences of the position ephemeris of the moon and sun for NDAYS days TDEL2 array order is $\delta^2 x_{a_1}, \delta^2 y_{a_1}, \delta^2 z_{a_1}, \delta^2 x_{\odot_1}, \delta^2 y_{\odot_1}, \ldots$

* a - moon
$\odot$ - sun

$\ldots, \delta^2 x_{\odot_{NDAYS}}, \delta^2 y_{\odot_{NDAYS}},$

$\delta^2 z_{\odot_{NDAYS}}$

Units of earth radii - mean of 1950.

TDEL4 — A 60-cell vector containing the fourth central differences of the position ephemeris of the moon and sun for NDAYS days TDEL4 array order is

$\delta^4 x_{a_1}, \delta^4 y_{a_1}, \delta^4 z_{a_1}, \delta^4 x_{\odot_1}, \delta^4 y_{\odot_1},$

$\delta^4 z_{\odot_1}, \ldots, \delta^4 x_{\odot_{NDAYS}}, \delta^4 y_{\odot_{NDAYS}},$

$\delta^4 z_{\odot_{NDAYS}}$

Units of earth radii—mean of 1950.

/EPHCOM/

XJD — A 10-cell vector containing NDAYS Julian dates. Each Julian date is input mod 2,430,000.0. XJD array order is

$JD_1, JD_2, JD_3, \ldots, JD_{NDAYS}$

3. Calling sequence

—

C. Output

1. Blank COMMON

—

2. Labeled COMMON

—

3. Calling sequence

—

D. Error/action messages

1. Off-line comment

"NO. OF EPHEMERIS DAYS LESS THAN 4, TURN BODIES OFF"

2. On line comment

—

3. Action

If the number of lunar-solar ephemeris days (NDAYS) is greater than 0 and less than 4, the off-line comment is printed and NDAYS is set equal to 0, which in effect turns off computation of perturbative accelerations due to the moon and sun.

SUBROUTINES USED

A. Library

—

B. Program

—

SUBROUTINE IDENTIFICATION

A. Title

REJECT

B. Segment

NRTPOD

C. Called by Subroutines

RADR

DCITER

FUNCTION

Function is to monitor the acceptance or rejection of an observation in the differential correction process. An observation may be rejected by any of the following criteria:

1) Deletion of the residual by number through the use of the DELET input card.
2) An observation weight of 0.
3) Failure of the residual to pass the gross outlier test ($N*\sigma$).
4) Failure of the residual to pass the K*RMS test.
5) Time from epoch greater than some DTMAX (this editing is done in subroutine DCITER).

Subroutine REJECT has a second entrance which computes the RMS by observation type to be used on the next iteration.

USAGE

A. Calling Sequence

Call REJECT (I1, I2, I3, I4)

B. Input

1. COMMON

NITCT	Current iteration count
PSIG	Observation weight; σ_R, σ_A, σ_E, $\sigma_{\dot{R}}$
PRESDT	Array containing the unweighted residuals (ΔR, ΔA, ΔE, $\Delta \dot{R}$)
NIDLED	Location of first cell of the array of residual deletion numbers in variable storage
NIDENT	Number of entries in the NIDLED array

CKRMS	RMS multiplier for the K*RMS rejection criterion (Kis nominally set to 1.5)
CNSIG	N multiplier for the N* σ gross outlier rejection criterion (N is nominally set to 1000.)
VSTR	Variable storage array

2. Calling Sequence

I1	A number 1-4 referring to the type of observation being tested I1 = 1 Range = 2 Azimuth = 3 Elevation = 4 Range rate
I3	Entrance flag I3 = 1 for normal entrance editing tests I3 = 2 to calculate RMS for each data type at the end of the iteration
I4	Residual number

C. Output

1. COMMON

PRMS	Array containing the RMS by observation type to be used on the next iteration
PDELFG	Four-cell array corresponding to the data types (R, A, E, $\dot{R}$) containing in each cell either 1) Word of blanks indicating the observation has been accepted 2) Word containing N indicating the observation residual has failed the gross outlier test (N*σ) 3) Word containing K indicating the observation residual has failed the K*RMS test 4) Word containing * indicating the observation was deleted by an input DELET list 5) Word containing S indicating the observation was deleted due to an observation weight being zero or negative

2. Calling Sequence

I2	= 0 residual passed all editing tests and has been accepted
	= 1 residual failed one of the editing tests and was rejected

D. Error/Action Messages

SUBROUTINES USED

A. Library

ABS

SQRT

B. Program

PASTOR	Routine to set up PDELFG array

METHOD/EQUATIONS

Compute the following for the I1 type observation:

$$
\begin{aligned}
I1 &= 1 \quad \Delta R \\
&= 2 \quad \Delta A \\
&= 3 \quad \Delta E \\
&= 4 \quad \Delta \dot{R}
\end{aligned}
$$

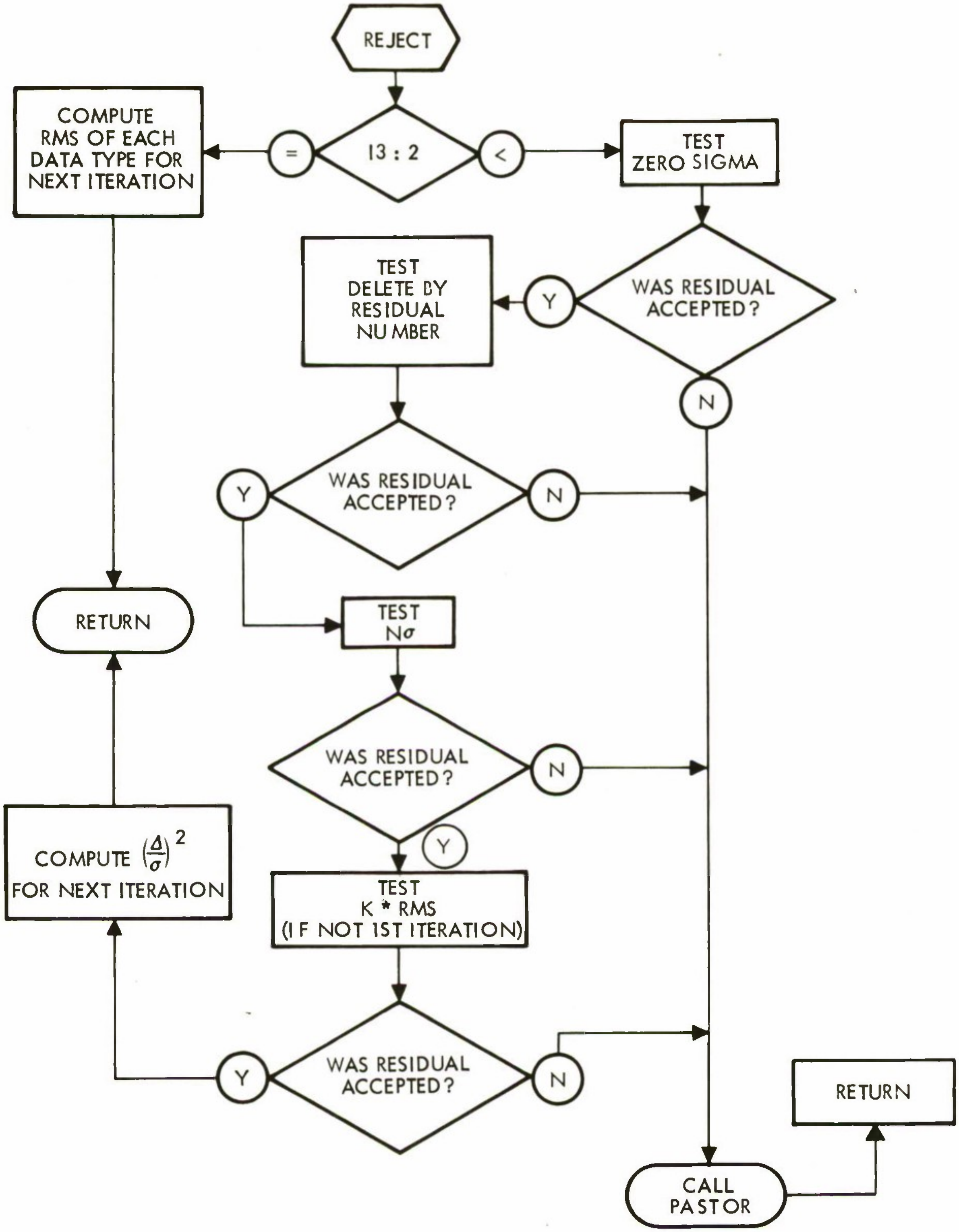


Figure 5-36. REJECT Flow Diagram

SUBROUTINE IDENTIFICATION

A. Title

RMAX

B. Segment

NRTPOD Partials - least square

C. Called by subroutine

PAGE 1

FUNCTION

Before a line of residuals is printed RMAX checks the magnitude of each output quantity. If the number overflows the prescribed format, a string of 9's is substituted.

USAGE

A. Calling sequence

Call RMAX

B. Input

1. COMMON

TEMP (1)	residual in R
TEMP (2)	residual in A
TEMP (3)	residual in E
TEMP (4)	residual in $\dot{R}$
TEMP (5)	residual in u
TEMP (6)	residual in v
TEMP (7)	residual in w
TEMP (8)	$\sqrt{\Delta u^2 + \Delta v^2 + \Delta w^2}$
TEMP (9)	β

C. Output

A signal number of all 9's replaces the input value in the appropriate TEMP location if the residual overflows.

SUBROUTINES USED

1. Library

   .FXEM.

2. Program

   —

SUBROUTINE IDENTIFICATION

A. Title

RPRESS

B. Segment

MHESPOD
PREMOD
NRTPOD

C. Called by subroutine

DAUX

FUNCTIØN

To compute the perturbative acceleration on a spacecraft due to direct radiation pressure from the sun and reflected radiation from the earth.

USAGE

A. Calling sequence

CALL RPRESS

B. Input

1. CØMMØN

/MESCØM/

TLIST	Numerical integration working storage array
XN	Positions of the moon, sun referenced to the earth
TEMP	Temporary working storage
DBASE	Days from 1950 to midnight day of epoch
TR	R - radius magnitude from vehicle referenced to the earth
CPI	π - radians
SGAMAM	$= E_o \, S' \, \gamma A/m \quad (\text{e. r.}^3/\text{min}^2)$

2. **Calling** sequence

—

C. Output

1. CØMMØN

/MESCØM/

TRPRES — Three-cell array containing the acceleration due to radiation pressure in the x, y, and z directions.

2. Calling sequence

D. Error/action messages

—

SUBRØUTINES USED

A. Library

SQRT

SIN

CØS

B. Program

EVERT

UVECT

DØT

ATNQ

EQUATIONS

$\vec{H} = x_s\vec{i} + y_s\vec{j} + z_s\vec{k}$ — ECI position vector of sun

$\vec{R} = x\vec{i} + y\vec{j} + z\vec{k}$ — ECI position vector of vehicle

$$\cos \beta_s = \vec{H} \cdot \vec{R} / |H| |R|$$

$$\cos \beta_o = + \frac{\sqrt{R^2 - 1}}{-R}$$

Reflected flux factor

$$Er/E_o \equiv 0.4\, R^2$$

Attenuation to reflected flux factor

$$\alpha = \frac{1}{2}\left[1 + \cos \frac{\pi}{2}\left(\frac{\beta_s - \beta_o}{\pi/2 - \beta_o}\right)\right]$$

$$E_r = E_o \cdot (E_r/E_o)^{\alpha}$$

Direct radiation acceleration

$$H^2\ddot{x}_d = E_o(x - x_s)/H$$

$$H^2\ddot{y}_d = E_o(y - y_s)/H$$

$$H^2\ddot{z}_d = E_o(z - z_s)/H$$

Reflected radiation acceleration

$$\ddot{x} = \left(-\frac{E_r x}{R} + H^2\ddot{x}_d\right) / H^2$$

$$\ddot{y} = \left(-\frac{E_r y}{R} + H^2\ddot{y}_d\right) / H^2$$

$$\ddot{z} = \left(-\frac{E_r z}{R} + H^2\ddot{z}_d\right) / H^2$$

Region Tests

1. If vehicle is in Regions I or II,

   $\cos \beta_s > \cos \beta_o$

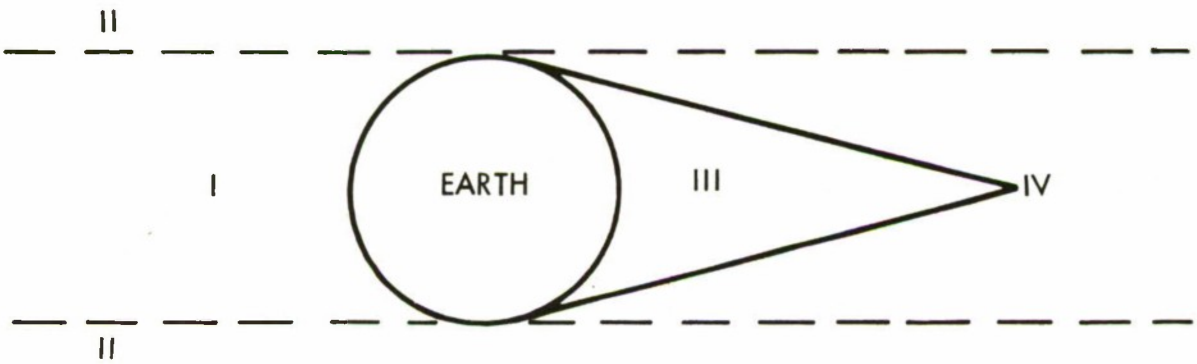
2. If vehicle is in Region II,

   $-\cos \beta_o > \cos \beta_s$

3. If vehicle is in Region IV,

   $R \left[\tan \gamma \cos(\pi - \beta_s) + \sin(\pi - \beta_s) \right] > 1$

   where $\tan \gamma = 0.0085$



RADIATION REGION MODEL

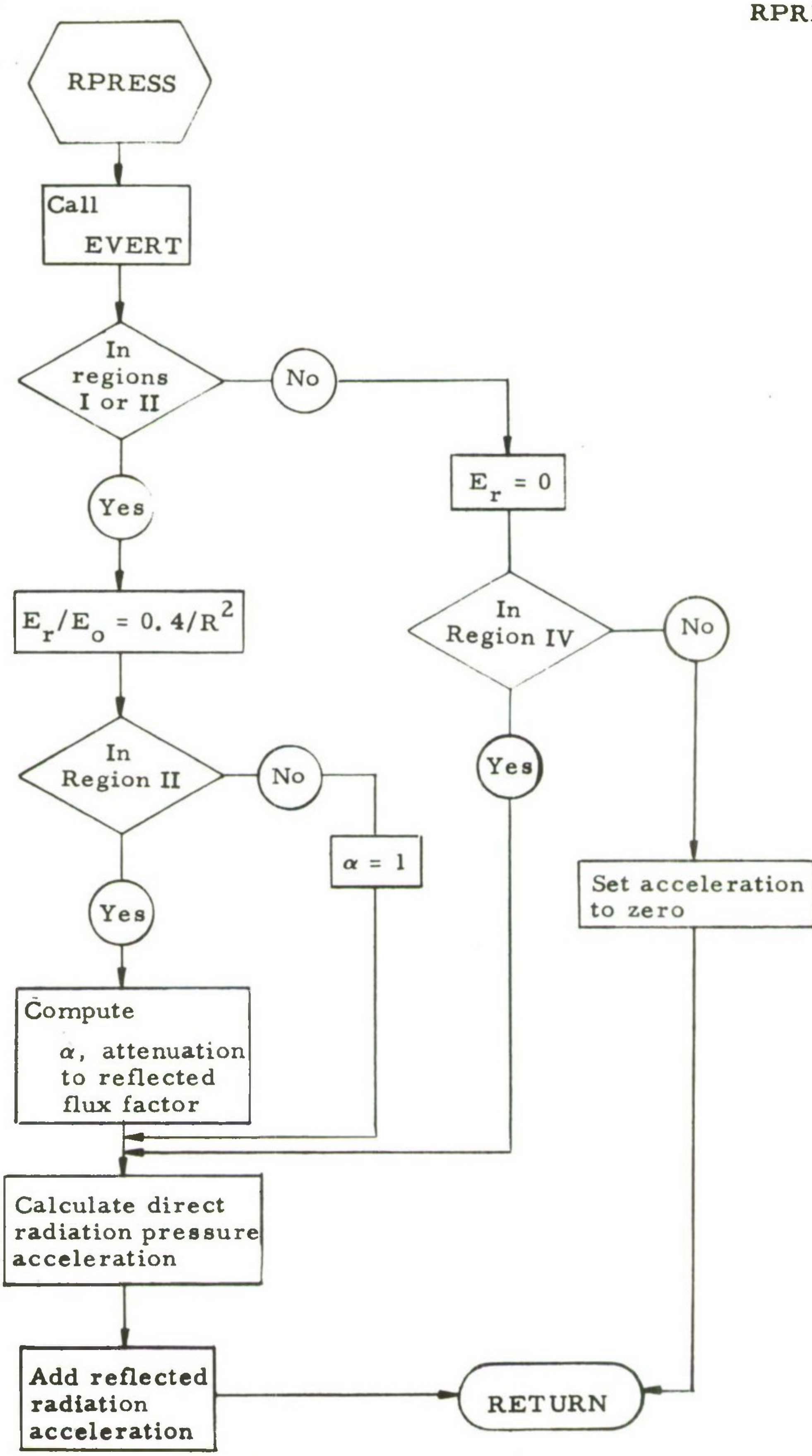


Figure 5-37. RPRESS Flow Diagram

SUBROUTINE IDENTIFICATION

A. Title

SDELET

B. Segment

NRTPOD - Input processor

C. Called by subroutine

INPUT

FUNCTION

The function is to move observation deletion numbers from DATA storage starting at DATA (595) to IVSTR variable storage starting at IVSTR (NIDLED).

USAGE

A. Calling sequence

CALL SDELET

B. Input

1. Blank COMMON

NIDLED	Identifies the starting location in variable storage of where the observation deletion table begins
NIDENT	Number of entries in the NIDLED list

2. Labeled COMMON

/INPP/

DATA	Input buffer storage

3. Calling sequence

—

C. Output

1. Blank COMMON

—

2. Labeled COMMON

/VSTR/

IVSTR (NIDLED - NIDENT)	Variable storage containing pairs of residual numbers for deletion purposes

3. Calling sequence

—

D. Error/action messages

—

SUBROUTINES USED

A. Library

—

B. Program

—

SUBROUTINE IDENTIFICATION

A. Title

SELECT

B. Segment

MHESPOD

C. Called by subroutine

MESPOD

FUNCTION

This subroutine selects the next time of an observation to which the numerical integration is to be carried.

USAGE

A. Calling sequence

Call SELECT

B. Input

1. COMMON

PUBS	Sensor number, time, R, A, E, $\dot{R}$, type
TEPOCH	Epoch time, minutes from midnight
TLIST	Numerical integration working storage
TMINUS	Flag to indicate integration times before epoch
TUBSEF	EOF flag for reading observations

2. Calling sequence

—

C. Output

1. COMMON

TG	Time, minutes from 0^h of epoch day, to integrate

2. Calling sequence

—

D. Error/action messages

—

SUBROUTINES USED

A. Library

—

B. Program

SETIC	Initialize the integration list
UBSGET	Gets next observation time from variable storage

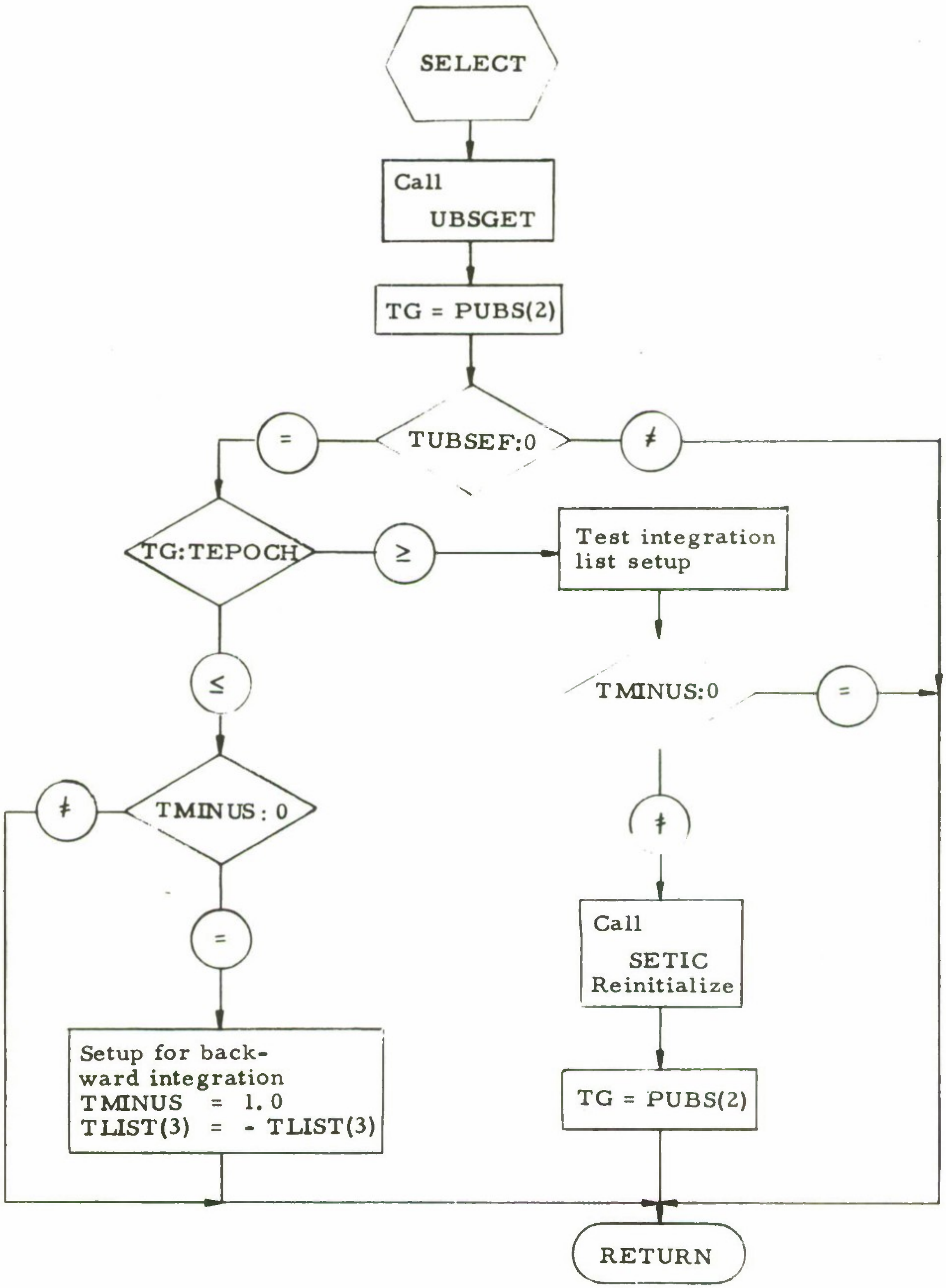


Figure 5-38. SELECT Flow Diagram

SUBROUTINE IDENTIFICATION

A. Title

SELECT

B. Program

NRTPOD

C. Called by Subroutines

TRJGEN

FUNCTION

To select the next output time for the trajectory package. This routine is used to select the next observation time during the Aerojet portion of NRTPOD, and the next DELTT time for the print-update option.

USAGE

A. Calling Sequence

Call SELECT

B. Input

1. COMMON

TEPOCH	Epoch time, minutes from 0 hours
DELTT	8 sets of Δt, T
KONTRL	= 1 if curve fit in progress, = 2 if trajectory print-update
TLIST	Integration list
NDTCT	Counter for DELTT array to indicate next set to be processed

2. Calling Sequence

—

C. Output

TG	The time of the next output, minutes from 0 hours day of epoch
PUBS	The next observation (if KONTRL = 1)
TUBSEF	Non-zero if the end of the observation tape has been sensed (if KONTRL = 1)

D. Error/Action Messages

—

E. Internal Storage

1. COMMON

TMINUS	This flag is used when there are pre-epoch times to be processed. When the first pre-epoch time is encountered this glag is set to 1 and the integration is initialized in the backward time direction. When the first post-epoch time is encountered, re-initialization of the integration at epoch will take place if TMINUS is set to 1. Initially, TMINUS is assumed 0.
NDTCT	Incremented internally

SUBROUTINES USED

A. Library

—

B. Program

UBSGET	Processes observation tape
SETIC	Initializes integration list at epoch

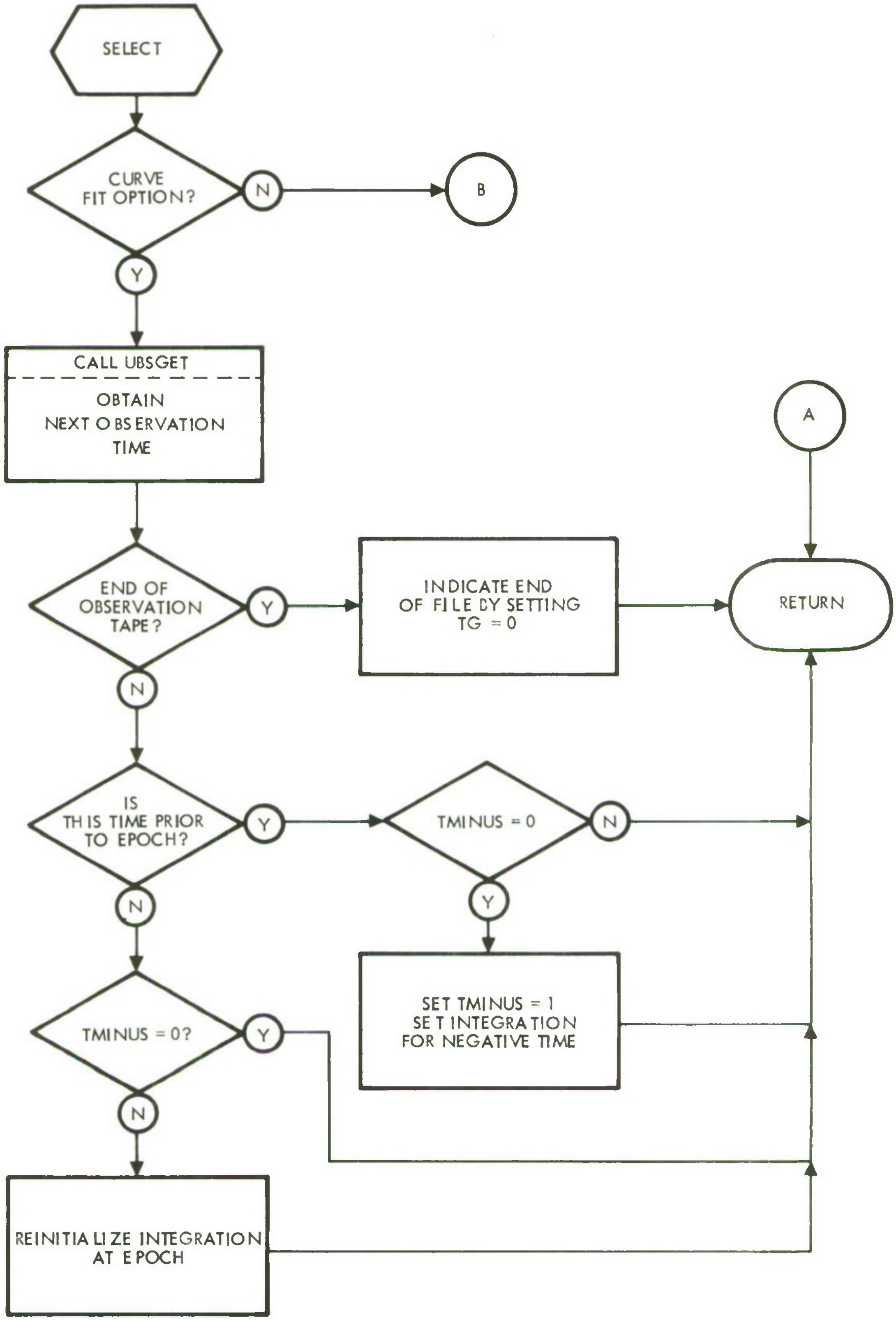


Figure 5-39. SELECT Flow Diagram

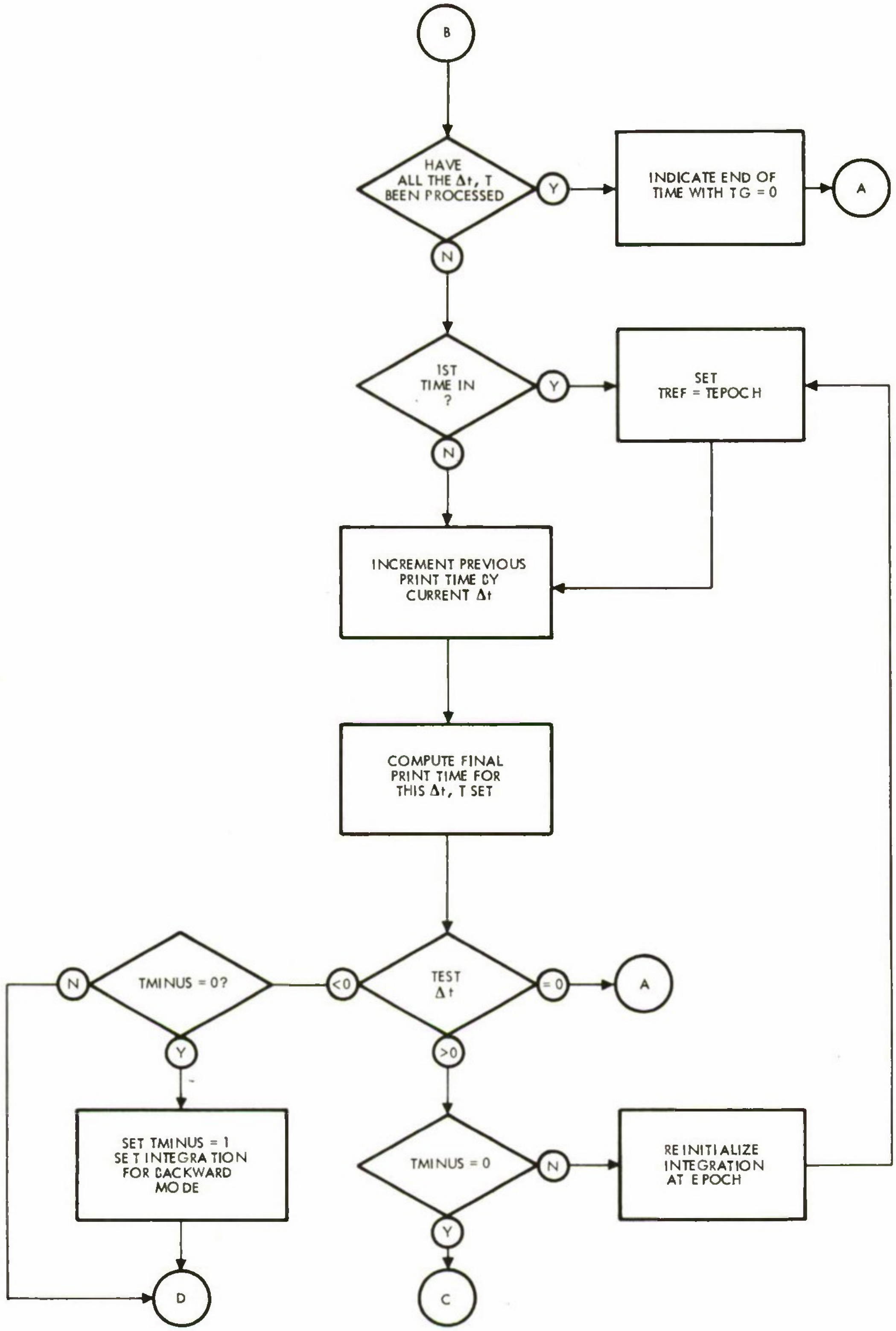


Figure 5-39. SELECT Flow Diagram (Continued)

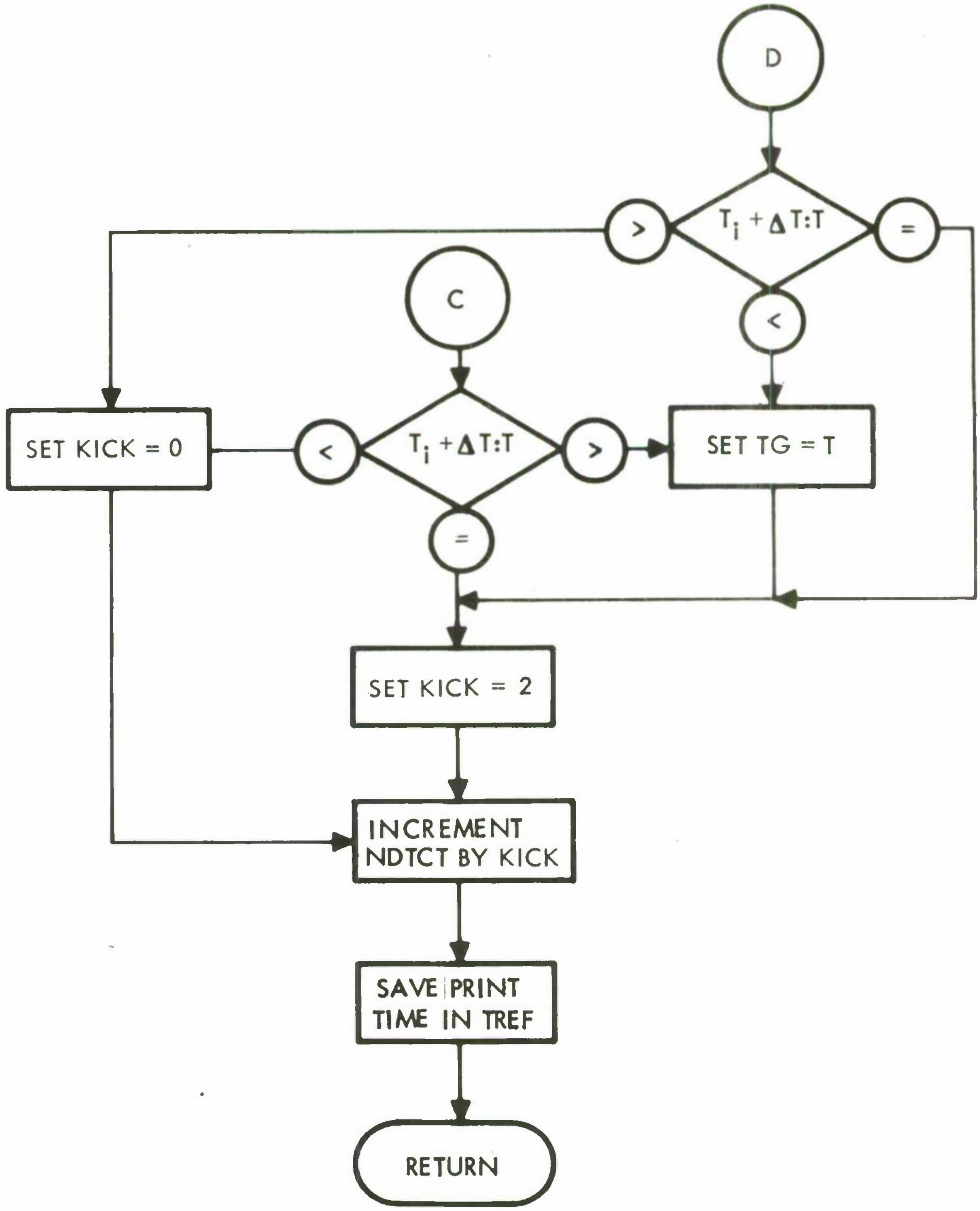


Figure 5-39. SELECT Flow Diagram (Continued)

SUBROUTINE IDENTIFICATION

A. Title

SENIN

B. Segment

PREMOD

C. Called by subroutines

LODSEN
SETCON

FUNCTION

To build the master sensor table, and the table containing parameters associated with each sensor to be used in the fit. Up to six unique stations may reside in the MST.

USAGE

A. Calling sequence

Call SENIN (TEMP, ERROR)

B. Input

1. COMMON

NSTAT	Location in VSTR of the start of the 60-cell master sensor table
VSTR	Block of storage containing vectors and arrays associated with the solution vector and the station information
CDEG	Degrees per radian
CMTER	Meters per earth radii
TALFAG	α_{go} . . . right ascension of Greenwich at 0 hours of the epoch day (radians)
CBE	Semi-minor axis of the geoid (earth radii)

2. Calling sequence

TEMP(1)	Station ID (BCD, 3 characters, left adjusted)
TEMP(2)	Station geodetic latitude (deg) . . . positive North
TEMP(3)	Station longitude (deg) . . . positive East
TEMP(4)	Station height (meters) above mean geoid

C. Output

1. COMMON

VSTR NSTAT	The master sensor table from VSTR (NSTAT) – VSTR (NSTAT + 59)

2. Calling sequence

ERROR	= 0	Station information entered into MST.
	= 1	No room in MST for this station.

D. Error/action message

—

E. Internal storage

A B	Auxiliary parameters used in station geocentric position. (See equations)

SUBROUTINES USED

A. Library

SIN
SQRT
COS

B. Program

PIMOD Insures angle between 0 and 2π.

COMMENTS

The routine will replace the information in the MST for the current station if a match on ID is found, otherwise the information is phased in the next available position in the MST.

A typical entry in the MST appears as follows:

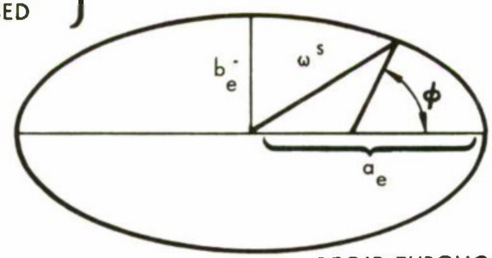
VSTR (NSTAT)	=	Station ID (BCD)
(NSTAT+1)	=	Station latitude (radians) . . . ϕ
(NSTAT+2)	=	Station longitude (radians) . . . λ
(NSTAT+3)	=	Station height (earth radii) . . . h
(NSTAT+4)	=	$\cos\phi$
(NSTAT+5)	=	$\sin\phi$
(NSTAT+6)	=	$\alpha_{so} + \lambda$
(NSTAT+7)	=	w_1^s
(NSTAT+8)	=	w_3^s
(NSTAT+9)	=	Not used

EQUATIONS

To find the geocentric coordinates of the station:

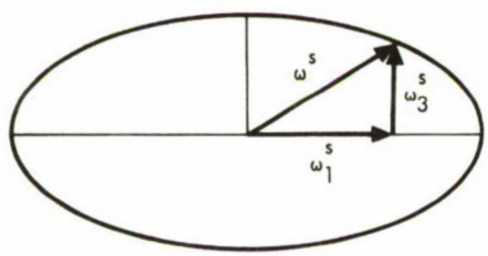
$$\left.\begin{array}{l}(NSTAT+6) = \alpha_{S_0} + \lambda \\ (NSTAT+7) = \omega_1^S \\ (NSTAT+8) = \omega_3^S \\ (NSTAT+9) = \text{NOT USED}\end{array}\right\}\ \text{SEE EQUATIONS}$$

ϕ = GEODETIC LATITUDE



GEOID THROUGH MERIDIAN OF STATION

ω^S HAS 2 COMPONENTS



TO FIND THE GEOCENTRIC COORDINATES OF THE STATION:

IF $A_S = (\cos^2\phi + b_e^2 \sin^2\phi)^{-1/2}$

$$B_S = \left(\sin^2\phi + \frac{1}{b_e^2}\cos^2\phi\right)^{-1/2}$$

then

$$w_1^s = (a_e A_s + h)\cos\phi$$

$$w_3^s = (b_e A_s + h)\sin\phi$$

SUBROUTINE IDENTIFICATION

A. Title

SENIN

B. Segment

NRTPOD - Input Processor

C. Called by subroutines

LODSEN

FUNCTION

This subroutine moves input sensor location parameters from buffer storage to working storage, computes the number of sensors and sets up the master sensor table with scaled units and values.

USAGE

A. Calling sequence

CALL SENIN

B. Input

1. Blank COMMON

CDEG	degrees/radian
CMTER	meters/e.r.
CBE	b_e
NUBS	Identifies the starting location of the observation table
NSTAT	Identifies the starting location of the master sensor table
NPR	Total number of parameters to solve for
NDPR	Number of all differential + initial parameters to solve for (Category 1)
TALFAG	αg_o for midnight day of epoch (radians)

2. Labeled COMMON

/TEMP/	
TEMP (1)	Sensor ID (left adjusted)
TEMP (2)	Sensor latitude (deg)
TEMP (3)	Sensor longitude (deg)
TEMP (4)	Sensor height (meters)
/INPP/	
DTMP	Saves station number and code word for those stations with code word $\neq 0$

3. Calling sequence

—

C. Output

1. Blank COMMON

—

2. Labeled COMMON

/VSTR/

VSTR (NSTAT)	Sensor ID
(NSTAT + 1)	Latitude (radians)
(NSTAT + 2)	Longitude (radians)
(NSTAT + 3)	Altitude (e. r.)
(NSTAT + 4)	Cos ϕ*
(NSTAT + 5)	Sin ϕ*
(NSTAT + 6)	$\alpha g_o + \lambda$ (radians)
(NSTAT + 7)	W_1 S (e.r.)
(NSTAT + 8)	W_3 S (e.r.)
(NSTAT + 9)*	Code word for the particular station identified by VSTR (NSTAT)
(NSTAT + 10)	= 0.0
(NSTAT + 11)	= 0.0

*VSTR (NSTAT + 9) is the code word given in the master sensor table for each sensor telling the program when to look in the IVSTR (NPRCD) array for additional information concerning Category 2 variables being solved for the particular sensor. If the code word of a sensor equals zero, then no Category 2 variables are being considered for the sensor. If the code word of a sensor is non zero, it has the following form:

A * 100.0 + B

A and B refer to the starting and stopping points in the IVSTR (NPRCD) array where the program can find the numbers identifying Category 2 variables which are being solved for this sensor.

3. Calling sequence

—

D. Error/action messages

—

SUBROUTINES USED

A. Library

COS
SIN
SQRT

B. Program

PIMOD Determines principle value of angle between 0 and 2π

MATCH Compares 2 cells for exact match

EQUATIONS

Same as in Espod Mathematical and Subroutine Description

SUBROUTINE IDENTIFICATION

A. Title
SENRD

B. Segment
PREMOD

C. Called by subroutine
LODSEN

FUNCTION

To read the three types of MHESPOD station location cards. The routine reads cards until a type 1 card (station location) is read or the end of sensor card indicator (station ID = END) is sensed. If a type 2 (biases) or 3 (sigmas) is read, the data is entered into the BIAS array for later processing. If no room remains for this station in BIAS, an error comment is printed and the data ignored.

USAGE

A. Calling Sequence
CALL SENRD (TEMP)

B. Input

1. Common

KIN	Logical number of the input device
KOUT	Logical number of the output device

2. Calling Sequence

C. Output

1. COMMON

A typical entry in the BIAS is:

BIAS (1) Station ID
(2) Range bias (km)
(3) Azimuth bias (deg)
(4) Elevation bias (deg)
(5) Range rate bias (km/sec)
(6) Not used
(7) Range σ (km)

BIAS (8) Azimuth σ (deg)
BIAS (9) Elevation σ (deg)
BIAS (10) Range rate σ (km/sec)

2. Calling Sequence

TEMP (1) Station ID (BCD . . .3 character ... left adjusted)
(2) Station geodetic latitude (deg)
(3) Station longitude (deg)
(4) Station height (meters)
(7) Type (=1)

D. Error/action messages

If there is no room for a given station in BIAS, the following message is printed:

NO ROOM IN BIAS TABLE FOR STATION XXX

SUBROUTINE USED

A. Library

—

B. Program

—

EQUATION

None

SENRD

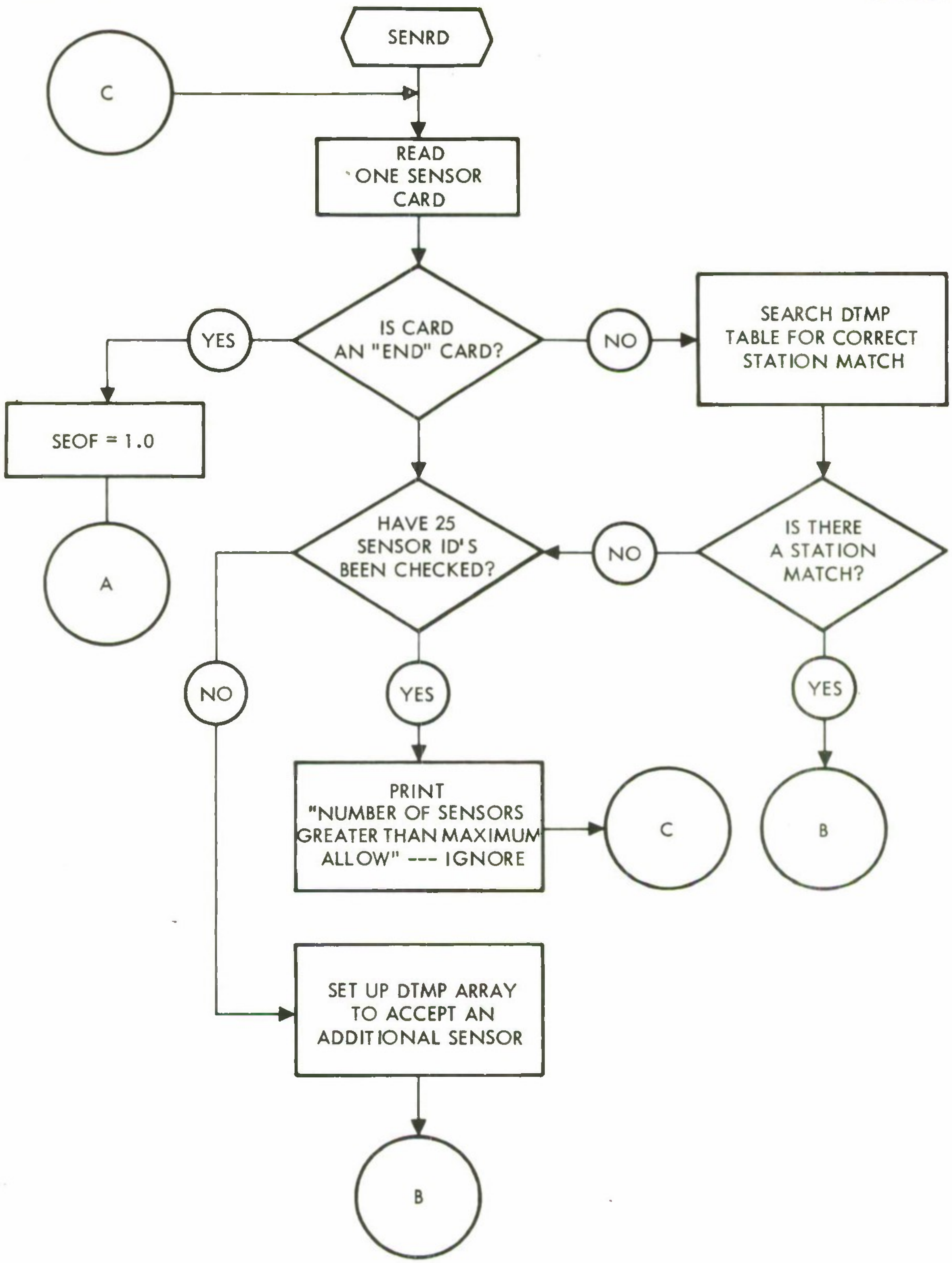


Figure 5-40. SENRD Flow Diagram

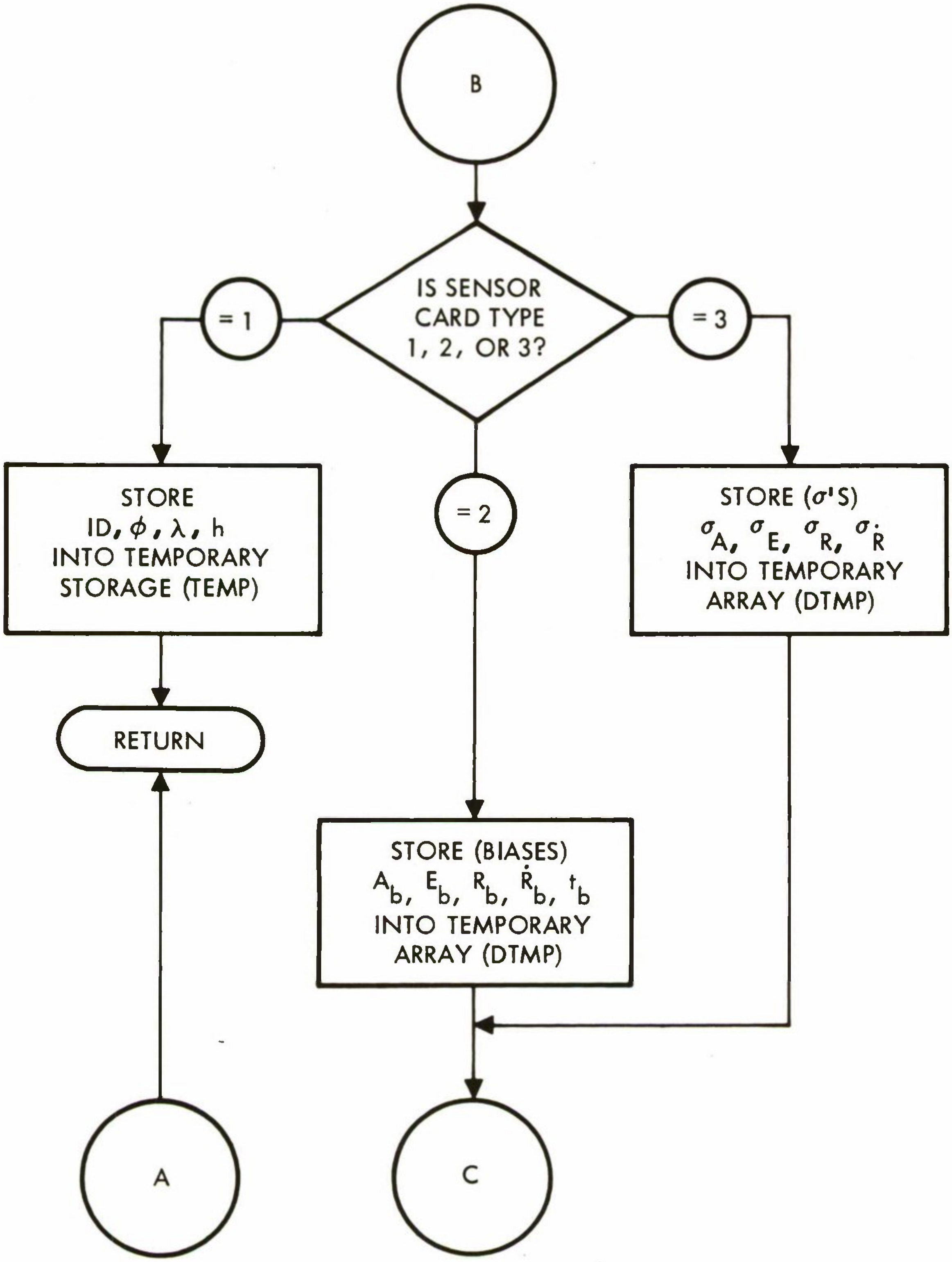


Figure 5-40. SENRD Flow Diagram (Continued)

SUBROUTINE IDENTIFICATION

A. Title

SENRD

B. Segment

NRTPOD - Input processor

C. Called by subroutine

LODSEN

FUNCTION

Function is to read the sensor cards (3 types) and to build a temporary buffer (DTMP) for biases and weights by station.

USAGE

A. Calling sequence

CALL SENRD (SEOF)

B. Input

1. Blank COMMON

KIN	Symbolic input tape
KOUT	Symbolic output tape
PREFLG	NRTPOD control flags (col 31 - 40 on JDC)

2. Labeled COMMON

/TEMP/	
TEMP	Internal temporary storage

3. Calling sequence

—

C. Output

1. Labeled COMMON

/INPP/	
NDTMP	Counter on DTMP buffer for biases and weights by station.
DTMP (51)	Station ID
(52)	Azimuth bias (deg)
(53)	Elevation bias (deg)
(54)	Range bias (km)
(55)	Range bias (km/sec)

(56)	time bias (sec)
(57)	σ_R standard deviation in range
(58)	σ_A standard deviation in azimuth
(59)	σ_E standard deviation in elevation
(60)	$\sigma_{\dot{R}}$ standard deviation in range rate
(61 ... 70) ... (70 ... 80)	Repeated for each input sensor (Maximum of 25 sensors allowed)

2. Calling sequence

SEOF	Flag indicating whether all sensor cards have been read. = -1. More sensors to be read = +1. END sensor card has been detected. No more sensor cards to be read.

D. Error/action messages

1. Off-line comment

"NO. OF SENSORS GREATER THAN MAX ALLOW. --- IGNORE."

2. On-line comment

—

3. Action

Ignores processing of previous sensor data, and proceeds to the next sensor card.

SUBROUTINES USED

A. Library

—

B. Program

—

SUBROUTINE IDENTIFICATION

A. Title
SETCON

B. Segment
PREMOD

C. Called by subroutines
PREMOD

FUNCTION

To preset the program constants and build in the nominal values for various control and input parameters. The master sensor table is preset with the identification and station locations for Millstone Hill, Haystack Hill and Kwajalein. Pseudo variable storage assignment are computed and the BDNS and NSCALE vectors are set up.

USAGE

A. Calling sequence
CALL SETCON

B. Input
1. COMMON

—

2. Calling sequence

—

C. Output
1. COMMON

Name	Pre-set values	
ZONAL	J_2, J_3, J_4	
SECT	J_2^2, λ_2^2	
CJ(1)	0.	J_1
CJ(2)	$.10823 \times 10^{-2}$	J_2
CJ(3)	$-.230 \times 10^{-5}$	J_3

SETCON

Name	Pre-set values	
CJ(4)	$-.18 \times 10^{-5}$	J_4
CJ(5)	$-.10 \times 10^{-6}$	J_5
CJ(6)	$.36 \times 10^{-6}$	J_6
CJ(7)	$-.39 \times 10^{-6}$	J_7
CJ(8)	$.24 \times 10^{-6}$	J_8
CJ(9)	0.	J_9
CJ(10)	$-.5 \times 10^{-6}$	J_{10}
CJ(11)	0.	J_{11}
CJ(12)	$.28 \times 10^{-6}$	J_{12}
CJNM(1, 1)	0	J_{11}
CJNM(2, 1)	0	J_{21}
CJNM(3, 1)	$.192 \times 10^{-5}$	J_{31}
CJNM(4, 1)	$.48 \times 10^{-6}$	J_{41}
CJNM(5, 1)	$.23 \times 10^{-6}$	J_{51}
CJNM(6, 1)	$.14 \times 10^{-6}$	J_{61}
CJNM(1, 2)	0	λ_{21}
CJNM(2, 2)	$.232 \times 10^{-5}$	J_{22}
CJNM(3, 2)	$.12 \times 10^{-6}$	J_{32}
CJNM(4, 2)	$.72 \times 10^{-7}$	J_{42}
CJNM(5, 2)	0	J_{52}
CJNM(6, 2)	$.7 \times 10^{-8}$	J_{62}
CJNM(1, 3)	-3.6	λ_{31}
CJNM(2, 3)	6.6	λ_{32}
CJNM(3, 3)	$.191 \times 10^{-5}$	J_{33}
CJNM(4, 3)	$.31 \times 10^{-7}$	J_{43}

Name	Pre-set values	
CJNM(5, 3)	0	J_{53}
CJNM(6, 3)	$.51 \times 10^{-8}$	J_{63}
CJNM(1, 4)	114.5	λ_{41}
CJNM(2, 4)	47.7	λ_{42}
CJNM(3, 4)	5.9	λ_{43}
CJNM(4, 4)	$.013 \times 10^{-6}$	J_{44}
CJNM(5, 4)	0	J_{54}
CJNM(6, 4)	$.1 \times 10^{-8}$	J_{64}
CJNM(1, 5)	72.9	λ_{51}
CJNM(2, 5)	0	λ_{52}
CJNM(3, 5)	0	λ_{53}
CJNM(4, 5)	0	λ_{54}
CJNM(5, 5)	0	J_{55}
CJNM(6, 5)	0	J_{65}
CJNM(1, 6)	-83.7	λ_{16}
CJNM(2, 6)	45	λ_{26}
CJNM(3, 6)	19.4	λ_{36}
CJNM(4, 6)	74.6	λ_{46}
CJNM(5, 6)	0	λ_{56}
CJNM(6, 6)	0	J_{66}
CLAMNN(1)	0	λ_{11}
CLAMNN(2)	-37.5	λ_{22}
CLAMNN(3)	51.3	λ_{33}
CLAMNN(4)	28.4	λ_{44}

Name	Pre-set values	
CLAMNN(5)	0	λ_{55}
CLAMNN(6)	0	λ_{66}
CWE	$4.37526906 \times 10^{-3}$	
CELLIP	1/298.3	
CMU	5.5303934×10^{-3}	
CGMR(1)	1/81.3015	
CGMR(2)	332951.3	
CFTER	2.0925738×10^{-7}	
CKMFT	$.3048 \times 10^{-3}$	
CKMER	6378.165	
CMTER	6378165.	
CDEG	57.29577951	
CFTNM	6076.1152	
CDAYMN(1)	31	
CDAYMN(2)	28	
CDAYMN(3)	31	
CDAYMN(4)	30	
CDAYMN(5)	31	
CDAYMN(6)	30	
CDAYMN(7)	31	
CDAYMN(8)	31	
CDAYMN(9)	30	
CDAYMN(10)	31	
CDAYMN(11)	30	
CDAYMN(12)	31	

Name	Pre-set values
CPI	3.1415926536
C2PI	6.2831853072
KOUT	3
KIN	2
KBCT	5
KADT	6
KDAP	7
CHMAX	64.
CHMIN	0.
CYMIN	.1
CER	$1. \times 10^{-8}$
CBE	1- CELLIP
CRASHE	$1. \times 10^{-8}$
NRRR	0
TSTEP	1.
CEP1	60.
NPR	6
NDPR	6
NAROW	1
NBDNS	8
NPAR	14
NDPAR1	20
NSCALE	26
NATA	32
NR	60

Name	Pre-set values
NSTAT	95
VSTR(NBDNS)	1×10^6/CFTER
VSTR(NBDNS+1)	1×10^6/CFTER
VSTR(NBDNS+2)	1×10^6/CFTER
VSTR(NBDNS+3)	60×10^4/CFTER
VSTR(NBDNS+4)	60×10^4/CFTER
VSTR(NBDNS+5)	60×10^4/CFTER
VSTR(NSCALE)	CKMER
VSTR(NSCALE+1)	CKMER
VSTR(NSCALE+2)	CKMER
VSTR(NSCALE+3)	CKMER/60
VSTR(NSCALE+4)	CKMER/60
VSTR(NSCALE+5)	CKMER/60
IMODFG	1
ISTPFG	1
RC	16.5
VC	.009
AN	5.25
CSUBA	.05
CSUBE	.05

2. Calling sequence

—

D. Error/action messages

—

E. Internal storage

XMHID (1)	Station code for Millstone Hill: MHbbbb
XMHID (2)	Millstone Hill latitude (deg)
XMHID (3)	Millstone Hill longitude (deg)
XMHID (4)	Millstone Hill height (meters)
XHHID (1)	Station code for Haystack Hill: HHbbbb
XHHID (2)	Haystack Hill latitude (deg)
XHHID (3)	Haystack Hill longitude (deg)
XHHID (4)	Haystack Hill height (meters)
XKWID (1)	Station code for Kwajalein: Kwbbbb
XKWID (2)	Kwajalein latitude (deg)
XKWID (3)	Kwajalein longitude (deg)
XKWID (4)	Kwajalein height (height)

SUBROUTINES USED

A. Library

—

B. Program

SENIN Enter station in master sensor table

EQUATIONS

None

SUBROUTINE IDENTIFICATION

A. Title

SETCON

B. Segment

NRTPOD - Input Processor

C. Called by subroutine

INPUT

FUNCTION

To set up nominal values of program control constants, potential model constants, scale factors, and symbolic tape assignments.

USAGE

A. Calling sequence

CALL SETCON

B. Input

1. COMMON

—

2. Calling sequence

—

C. Output

1. Blank COMMON

CWE	Earth's rotational rate (radians/min)
CELLIP	Ellipticity of the earth
CMU	GM of the earth (e.r.^{3}/min^2)
CGMR	GM ratios (MOON GM/EARTH GM, SUN GM/EARTH GM)
CFTER	ft/e.r.
CKMFT	km/ft
CKMER	km/e.r.
CMTER	meters/e.r.
CDEG	degrees/radian
CFTNM	ft/n mi
CNMER	n mi/earth radii
CDAYMN	12-cell array denoting the number of days in each month
CPI	π
C2PI	2π

KOUT	Output tape number (print)
KIN	Input tape number
MT	Observations tape number
NOUT	Scratch tape not used at present by NRTPOD
ITRJTP	Trajectory ephemeris tape number
CHMAX	Maximum integration step size
CHMIN	Minimum integration step size
CYMIN	Parameter for variable step integration
CER	Parameter for variable step integration
CBE	b_e = 1. - CELLIP
CRASHE CRASHM	Impact flags used by subroutine TRAJ
CJD50	Julian date Jan 0, 1950
COMLST	Size of variable storage
CFTEPS	RMS convergence criterion
DTMAX	Editing parameter - maximum allowable observation time from epoch (days)
TSTEP	Initial integration step size (min)
BFLAGS	Flags indicating bodies (moon and sun) to be considered
SKIP	If 0, always set FLVE = 0, if non-zero, set FLVE accordingly
CKRMS	A provision for editing residuals by input
CNSIG	N for $N \cdot \sigma$ deletion
NRRR	Ratio of Range-Kutla step to Cowell step
FLVE	If non-zero, skip VAREQ

2. Labeled COMMON

/INPP/

SECT	Array of cells used for callouts of the sectorial harmonics, non-zero to include the desired harmonic
CJ	Values of the coefficients of the zonal harmonics $J_2, \ldots, J_{12}$.
ZONAL	Array of cells used for callouts of the coefficients of the zonal harmonics
CLAMNN	Array containing the angles associated with the coefficients of the tesseral harmonics
CJNM	6 x 6 array containing the coefficients of the sectorial and tesseral harmonics and their associated angles

3. Calling sequence

—

D. Error/action messages

—

 SETCON

SUBROUTINES USED

A. Library

—

B. Program

—

SUBROUTINE IDENTIFICATION

A. Title

SETIC

B. Segment

MHESPØD
PREMØD

C. Called by subroutine

MESPØD
SELECT

FUNCTION

The function is to initialize the integration list and other parameters which must be re-initialized each time the integration is re-started.

USAGE

A. Calling sequence

Call SETIC

B. Input

1. CØMMØN

TEPØCH	Minutes from midnight to epoch
TSTEP	Starting step size for the numerical integration in minutes
TICRT	x, y, z, $\dot{x}$, $\dot{y}$, $\dot{z}$ of the vehicle at epoch in Earth radii and Earth radii per minute

2. Calling sequence

—

C. Output

1. CØMMØN

TMINUS	Flag indicating backward integration
PMAT, VMAT	Arrays used in variational equation formulation, initialized at 0

TG	Time to integrate to
FLVE	Flag for variational equations computation
TCRASH	Impact flag
TLIST	Numerical integration working storage

2. Calling sequence

—

D. Error/action messages

—

SUBROUTINES USED

A. Library

—

B. Program

DAUX
VPERT

EQUATIONS

None

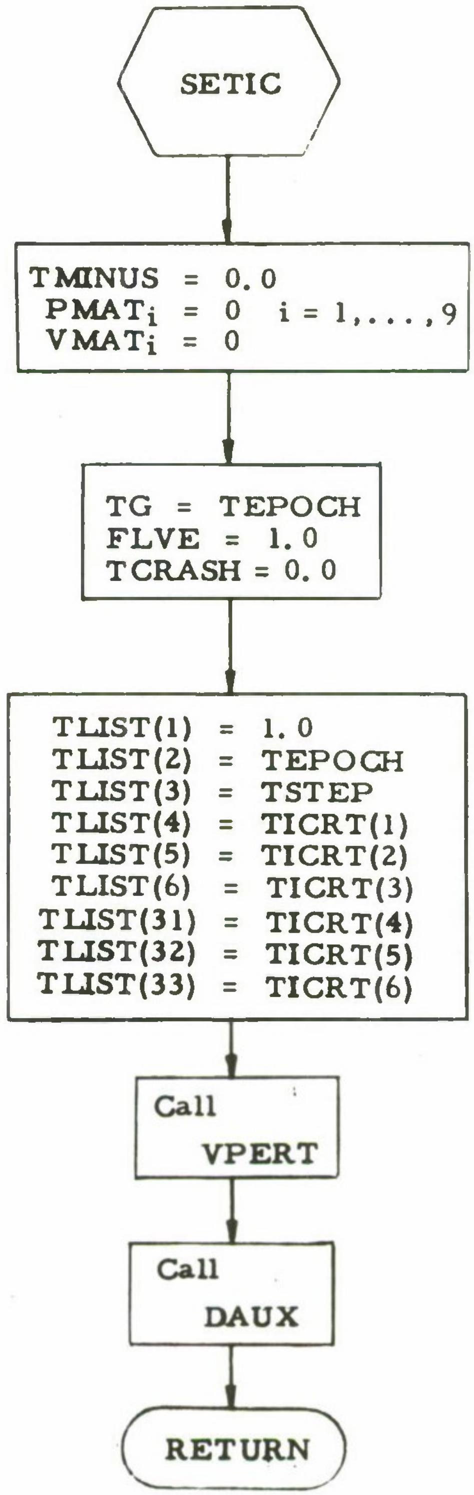


Figure 5-41. SETIC Flow Diagram

SUBROUTINE IDENTIFICATION

A. Title

SETIC

B. Segment

NRTPOD

C. Called by Subroutines

SELECT

TRJGEN

FUNCTION

The function is to initialize the integration list and other parameters which must be re-initialized each time the integration is re-started.

USAGE

A. Calling Sequence

Call SETIC

B. Input

1. COMMON

NDPR	Total number of Category I variables
TEPOCH	Minutes from midnight day of epoch
TSTEP	Starting step size for the numerical integration in minutes
TICRT	x, y, z, $\dot{x}$, $\dot{y}$, $\dot{z}$ of the vehicle at epoch in earth radii and e.r./min

2. Calling Sequence

—

C. Output

1. COMMON

TG	Time to integrate to (min)
TCRASH	Impact flag = 0 not impacted ≠ 0 impact
TLIST	Numerical integration working storage
TMINUS	Flag indicating backward integration
PMAT, VMAT	Arrays used in variational equation formulation, initialized at 0
FLVE	Flag for variational equations compatation

SETIC

2. Calling Sequence

—

D. Error/Action Messages

—

SUBROUTINES USED

A. Library

—

B. Program

DAUX

VPERT

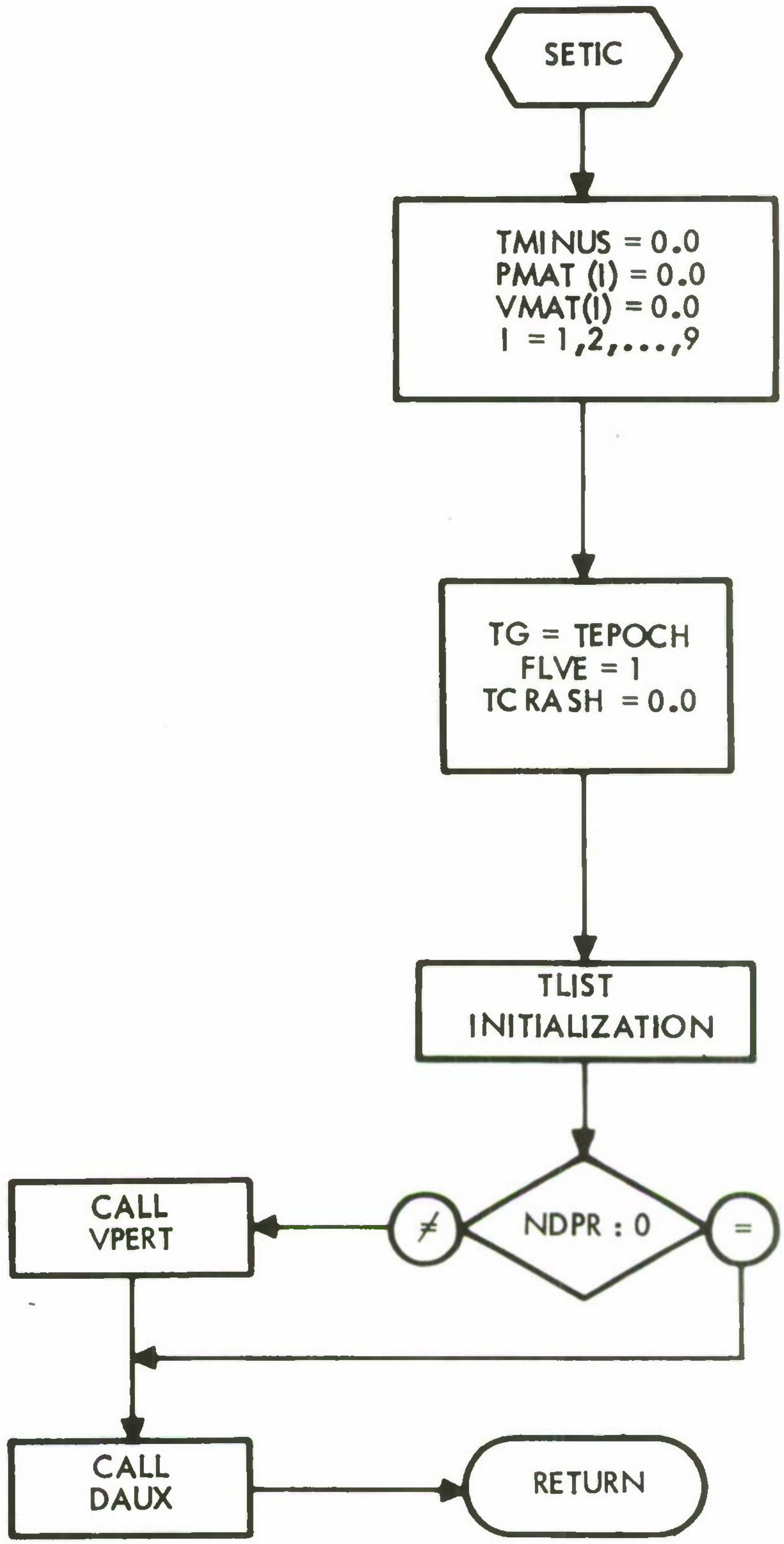


Figure 5-42. SETIC Flow Diagram

SUBROUTINE IDENTIFICATION

A. Title

SETSTR

B. Segment

PREMOD

C. Called by subroutine

PREMOD

FUNCTION

To convert preset and input values from external to internal units. The a priori normal matrix (SMAT) is processed here.

USAGE

A. Calling sequence

CALL SETSTR

B. Input

1. COMMON

IRADT	Column 21 of the JDC, non-zero if ADT used for restart
RC	DAP critical range in kilometers
VC	DAP critical range rate in kilometers per second
AN	DAP smoothing time in seconds
TBIAS	DAP time bias in seconds
RB	DAP range bias in kilometers
VB	DAP range rate bias in kilometers/second
EB	DAP elevation bias (deg)
AB	DAP azimuth bias (deg)
SIGMH(1)	Standard deviation for Millstone Hill range data (km)
SIGMH(2)	Standard deviation for Millstone Hill azimuth data (deg)
SIGMH(3)	Standard deviation for Millstone Hill elevation data (deg)
SIGMH(4)	Standard deviation for Millstone Hill range rate data (km/sec)
IRESD	Column 34 of JDC, non-zero to record residuals on ADT
IPRCE	Column 35 of JDC, non-zero to record core ephemeris on ADT
PTB(1, 2, 3)	Value of the preliminary epoch (the point at which the search for time of rise is

PTB(1, 2, 3)(cont)	initiated) in days, hours, and minutes from the initial epoch
PTNULL(1, 2, 3)	Value of the pre-specified epoch in days, hours, and minutes from the initial epoch.
DRAGCD	If non-zero, the value of the drag coefficient C_d.
DRAGA	If non-zero, the effective area of the spacecraft, for use in calculating $\frac{C_d A}{m}$. (meters^2)
DRAGM	If non-zero, the mass of the spacecraft, for use in calculating $\frac{C_d A}{m}$. (kg)
CKMFT	km/ft
DRAG	If non-zero, the value of $\frac{C_d A}{m}$ in meters^2/kilogram
CMTER	Meters per earth radii.
RPGAM	γ in radiation pressure model.
RPA	Effective area of spacecraft for radiation pressure model (meters^2).
RPM	Mass of spacecraft for radiation pressure model (kg)
RADPR	$\gamma A/m$ for radiation pressure model.
SMAT	A 21-cell array containing the a priori $A^T A$ matrix in Cartesian coordinates $(x, y, z, \dot{x}, \dot{y}, \dot{z})$ stored upper triangular by rows. This matrix has units of kilometers and seconds.
NSCALE	Location in VSTR of scale vector for $x, y, z, \dot{x}, \dot{y}, \dot{z}$ vector and matrix conversions from external to internal units.
NPR	Number of parameters in solution vector (6).
NATA	Location in VSTR of $A^T A$, $A^T b$ matrix as derived from an ADT from a previous curve fit on MHESPOD. The matrix is stored augmented, upper triangular by rows.
DTYPE	Type of initial conditions.
SMELM	The mean elements from the SPADATS 6 card element set. (Angles in deg)
CDEG	Degrees per radian.

2. Calling sequence

—

C. Output

1. COMMON The following items are output in internal units

RC	2-way transit time in half-microseconds
VC	Doppler shift magnitude in cycles per second
AN	Computer time units
TBIAS	Minutes
RB	Earth radii
VB	Earth radii/minute
EB	Radians
AB	Radians
SIGMH(1)	Earth radii
SIGMH(2)	Radians
SIGMH(3)	Radians
SIGMH(4)	Earth radii/minute
IRESFD	Record residuals flag, for MHESPOD
IRCE	Record core ephemeris flag, for MHESPOD
TB	Preliminary epoch time (minutes from epoch)
TNULL	Epoch specification (minutes from epoch)
CDAD2M	$\frac{C_d A}{2m}$ in ft^2/slug
SGAMAM	$\frac{S\gamma A}{m}$ in $e.r^3/min^2$
SMAT	Stored lower triangular un-augmented in earth radii and minutes
SMELM	Angles in radians, mean motion, and rates in radians

2. Calling sequence

—

D. Error/action messages

None

E. Internal storage

CLIGHT	Speed of light (meters/second)
S	Solar constant (kgm meters/$second^2$)
CKGSG	kg/slug
F	Frequency of Millstone Hill transmitter in cycles per second

SUBROUTINES USED

A. Library

None

B. Program

JCS	Sets up working storage for potential calculation
HUMAH	Scales vector and matrices from internal to external units and vice versa

EQUATIONS

To convert range from kilometers to 2-way transit time:

$$R_{2\text{-way}} = \frac{R_{km} \cdot 1000 \cdot 4 \times 10^6}{C}$$

C = speed of light (meters/second)

To convert range rate from kilometers to second to doppler shift magnitude in cycles per second:

$$V_{doppler} = \frac{V_{range\ rate} \cdot 1000 \cdot 2 \cdot F}{C}$$

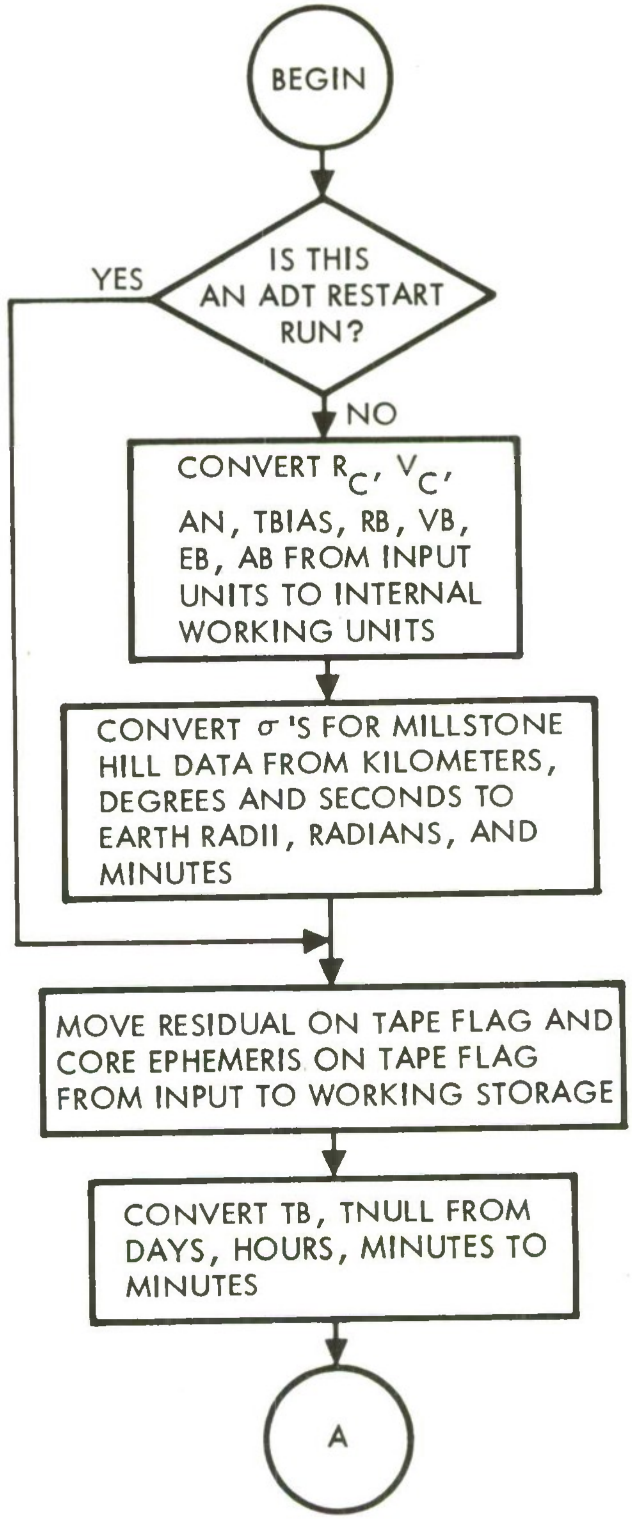


Figure 5-43. SETSTR Flow Diagram

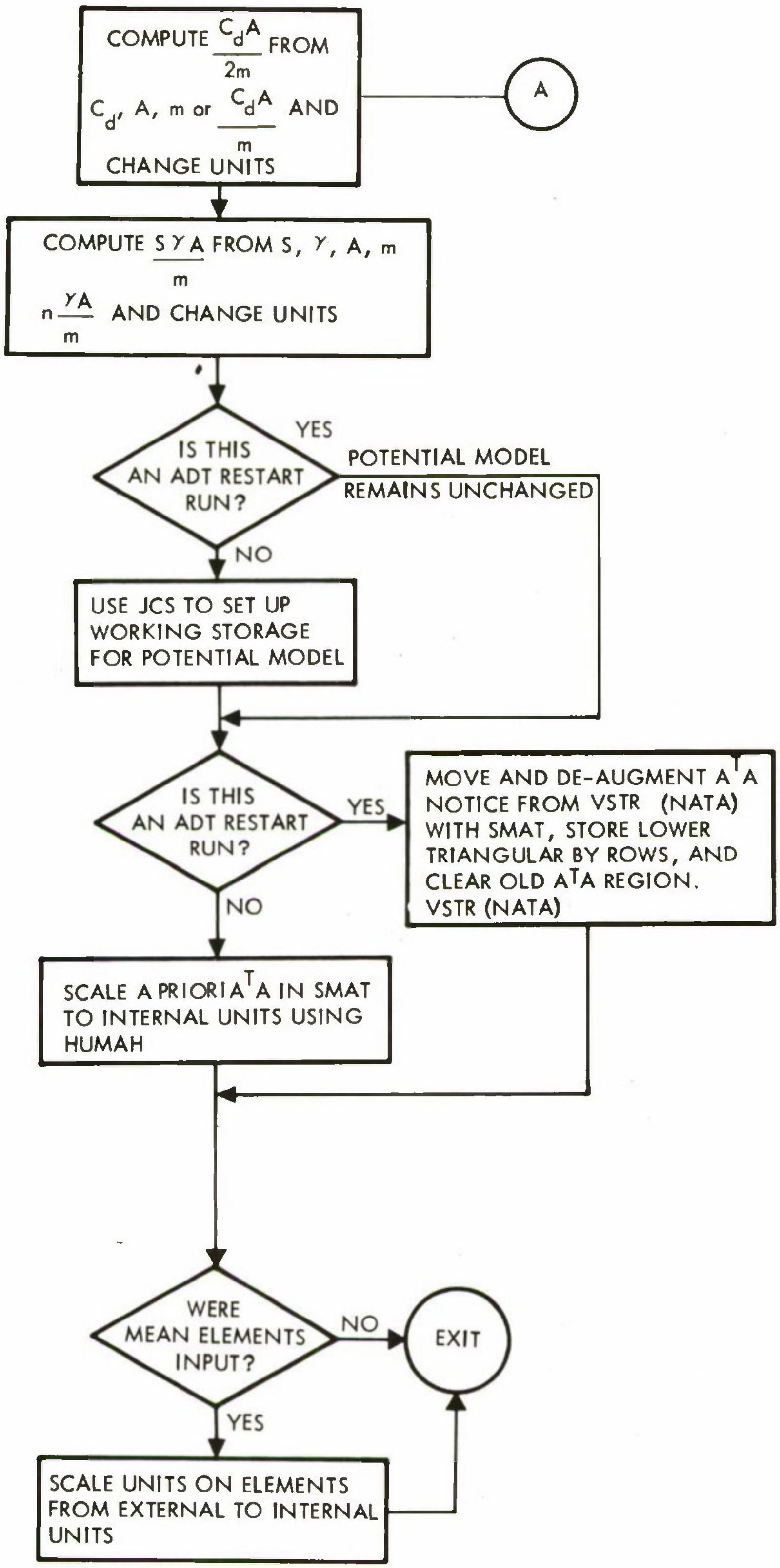


Figure 5-43. SETSTR Flow Diagram (Continued)

SUBROUTINE IDENTIFICATION

A. Title

SETSTR

B. Segment

NRTPOD - Input processor

C. Called by subroutine

DPRLM - Input Processor

FUNCTION

Function is to scale from external to internal units, the drag and radiation pressure parameters; and set up working storage for the simulation of the Earth's potential model.

USAGE

A. Calling sequence

CALL SETSTR

B. Input

1. Blank COMMON

CKMFT	km/ft
CMTER	meters/er

2. Labeled COMMON

/INPP/			
DRAG	Ballistic coefficient $\frac{C_D A}{m}\left(\frac{\text{meter}^2}{\text{kilogram}}\right)$		
DRAGCD	C_D	coefficient of Drag	DRAGCD DRAGA DRAGM may be input in place of DRAG
DRAGA	A	area in DRAG term (meter^2)	
DRAGM	m	mass in DRAG term (kilograms)	
RADPR	Radiation pressure parameter $\frac{\gamma A}{m}\left(\frac{\text{meters}^2}{\text{kilogram}}\right)$		

RPGAM	γ in RADPR, reflectivity constant.	RPGAM RPA RPM may be input in place of RADPR
RPA	A in RADPR, area of vehicle (meter^2)	
RPM	m in RADPR, mass of vehicle (kilograms)	

3. Calling sequence

—

C. Output

1. Blank COMMON

CDAD2M	$C_D A/2m$	Ballistic drag term ($ft^2/slug$) (internal units)
SGAMAM	$S\gamma A/m$	Radiation pressure parameter ($e.r.^3/min^2$)

2. Labeled COMMON

—

3. Calling sequence

—

D. Error/action messages

—

SUBROUTINES USED

A. Library

—

B. Program

JCS

SUBROUTINE IDENTIFICATION

A. Title

SETTAB

B. Segment

NRTPOD - Input processor

C. Called by subroutine

INPUT

FUNCTION

Function is to set up the VSTR (NIDP), VSTR (NPRCD), VSTR (NPBIS), VSTR (NSCALE), VSTR (NBDNS), and DTMP tables.

USAGE

A. Calling sequence

Call SETTAB

B. Input

1. Blank COMMON

CMTER	meters/e.r.
CDEG	deg/radian
CKMER	km/e.r.
CKMFT	km/ft
NIDP	Identifier for table indicating Category 1 type variables to be solved for
NBDNS	Starting location in VSTR for the bounds used by LEGS2 subroutine
NSCALE	Identifies the starting location of the list of conversion factors which convert all solution vectors and associated matrices from machine units to output units
NPR	Number of all parameters to solve for
NDPR	Number of all differential + initial parameters to solve for (Category 1)
NPRCD	Identifies table for definition of Category 2 variables to be solved for
NPBIS	Identifies table for current estimates of Category 2 variables

2. Labeled COMMON

/INPP/

DATA	Temporary input buffer specifying to this subroutine the CAT1 variables, CAT2 variables, bias estimates, scale vector and bounds vector.

3. Calling sequence

—

C. Output

1. Blank COMMON

—

2. Labeled COMMON

/INPR/	
DTMP	Buffer for station number and code word for those stations with code word ≠0
/VSTR/	
VSTR	Floating point variable storage
IVSTR	Fixed-point variable storage

3. Calling sequence

—

D. Error/action messages

—

SUBROUTINES USED

A. Library

—

B. Program

—

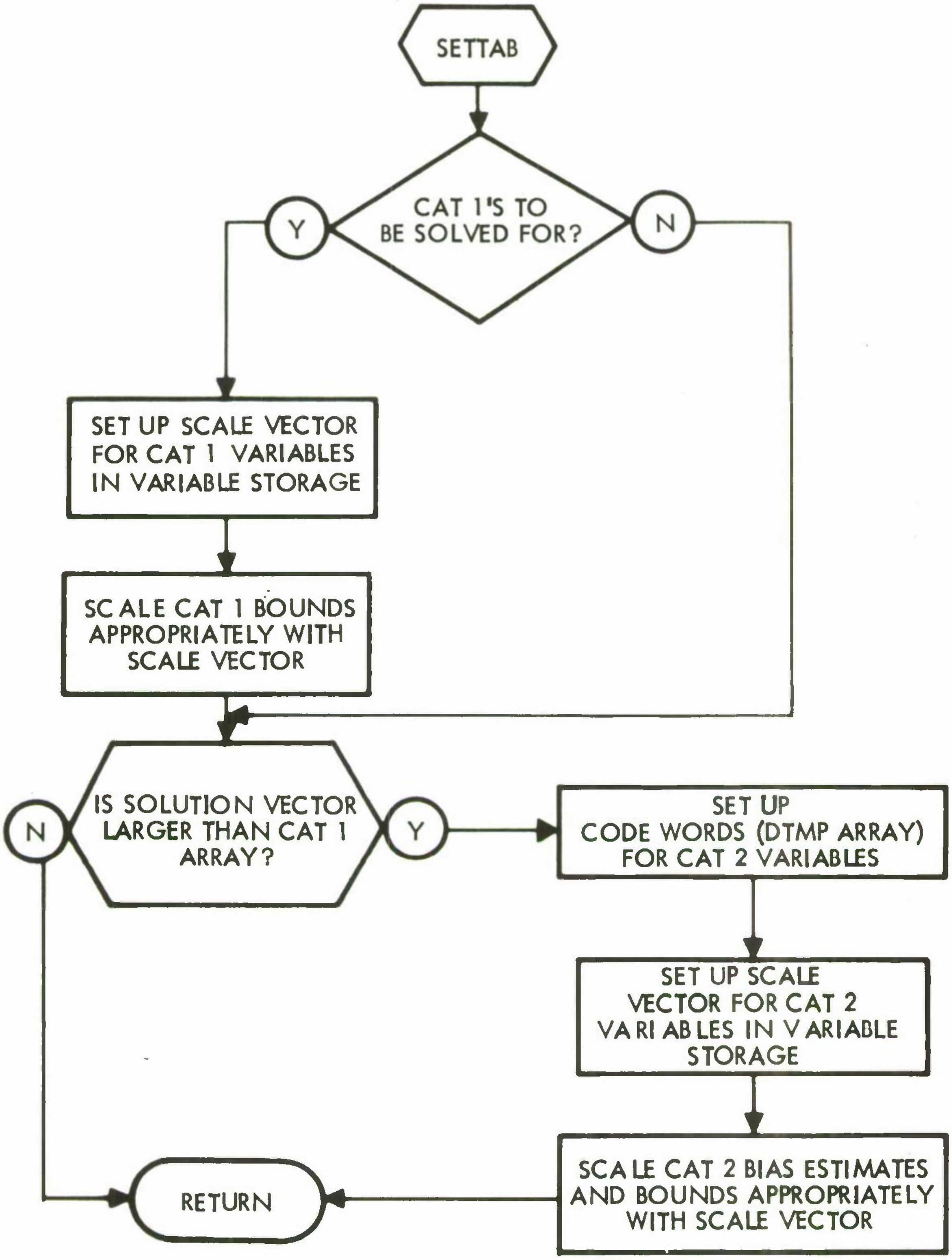


Figure 5-44. SETTAB Flow Diagram

SUBROUTINE IDENTIFICATION

A. Title

STSMAT

B. Segment

NRTPOD - Input Processor

C. Called by subroutine

INPUT

FUNCTION

The function is to convert the upper triangular S matrix in DATA storage from human units to machine units and then transfer to VSTR (NATA).

USAGE

A. Calling sequence

Call STSMAT

B. Input

1. Blank COMMON

NSCALE	Identifies the starting location of the list of conversion factors which convert all solution vectors and associated matrices from machine units to output units.
NPR	Total number of parameters to solve for
NATA	Identifies the starting location of where the triangular ATA is stored.
DCFLG	NRTPOD control flags, columns 41-50 of JDC.

2. Labeled COMMON

/INPP/

DATA	The a priori S matrix is input into thw DATA array in human units starting at DATA (102).

3. Calling sequence

—

C. Output

1. Blank COMMON

—

2. Labeled COMMON

/VSTR/

VSTR (NATA)	Identifies the starting location of where the upper triangular S matrix is stored in variable storage

3. Calling sequence

—

D. Error/action messages

—

SUBROUTINES USED

A. Library

—

B. Program

HUMAH	Converts a vector or a matrix from machine units to human units or vice versa

SUBROUTINE IDENTIFICATION

A. Title

SUPMAT

B. Segment

NRTPOD - Input processor

C. Called by subroutine

INPUT

FUNCTION

The function is to move the initial update matrix from temporary storage (DATA) to permanent storage VSTR (NR) and convert from human units to machine units.

USAGE

A. Calling sequence

Call SUPMAT

B. Input

1. Blank COMMON

NPR	Total number of parameters to solve for
NR	Identifies the starting location in variable storage of $(A^TA)^{-1}$
NSCALE	Identifies the starting location of the list of conversion factors which convert all solution vectors and associated matrices from machine units to output units

2. Labeled COMMON

/INPP/

DATA	Data array containing the a priori update matrix in output units starting at DATA (925)

3. Calling sequence

—

C. Output

—

D. Error/action messages

—

SUBROUTINES USED

A. Library

—

B. Program

HUMAH	Converts a vector or a matrix from machine units to human units or vice versa

SUBROUTINE IDENTIFICATION

A. Title

TPRLM

B. Program

NRTPOD

C. Called by Subroutine

TRJPAO

FUNCTION

The initialization routine for the trajectory, curve fit, and print-update segments. This routine is entered before the first iteration of the curve fit, and before the generation of the trajectory for the print-update segment.

USAGE

A. Calling Sequence

Call TPRLM

B. Input

1. COMMON

CKMER	Kilometers per earth radii
CDEG	Degrees per radii
NDPR	Number of CAT1 variables in solution
NPR	Total number of solution variables
NIDP	Start of CAT1 identifiers on VSTR
NPBIS	Start of VSTR table of initial bias estimates for CAT2 variables
DCFLG	Column 41-50 of the JDC
TNOMX	Initial trajectory condition in Cartesian coordinates (kilometers and seconds)
TNOMP	Initial trajectory conditions in polar coordinates (kilometer, seconds, degrees)
CDAD2M	$\frac{C_d A}{2m}$ (feet squared/slug)
KONTRL	= 1 for curve fit entrance, = 2 for print-update entrance

2. Calling Sequence

—

C. Output

1. COMMON

NPAR	The VSTR table of the initial values for each CAT1 and CAT2 variable
TICRT	The Cartesian initial trajectory conditions in earth radii and minutes
TIPOL	The polar initial trajectory conditions in earth radii, radians, and minutes
TSUSB	The best RMS initialized at 10^{33}
NITCT	The iteration count unitialized at 1 (if KONTRL = 1)
NDTCT	The DELTT pointer, initialized at 1 (if KONTRL = 2)

2. Calling Sequence

—

D. Error/Action Messages

—

E. Internal Storage

—

SUBROUTINES USED

A. Library

—

B. Program

—

SUBROUTINE IDENTIFICATION

A. Title

TRAJ

B. Program

NRTPOD

C. Called by Subroutine

TRJGEN

FUNCTION

Integrate the equations of motion and up to 24 variational equations to a specified time. The routine uses Runge-Kutta as a starter to build eighth order difference tables for a Cowell method of numerical integration. The routine will automatically exit with a flag set to indicate earth impact.

USAGE

A. Calling sequence

Call TRAJ(TN)

B. Input

1. COMMON

HMAX	Maximum allowable step size
HMIN	Minimum allowable step size
ER, YMIN	Step size test parameters; See method
TLIST	Input and storage, at output values consistent with T
CMU	GM of earth (Earth radii and minutes)
CRASHB	Ellipticity of earth
CRASHE	1×10^{-8}
CRASHM	Altitude below which impact test will be made (earth radii)
NDPR	The number of variational parameters in the integration list
NRRR	Non-zero if fixed step Runge-Kutta desired
SKIP	If 0, evaluate variational equations only on "predictor" steps

2. Calling sequence

TN	Time to integrate to (Minutes from epoch)

C. Output

1. COMMON

TRAJX(1-3)	x, y, z Output . . . consistent with TN or impact time
TRAJX(4-6)	$\dot{x}, \dot{y}, \dot{z}$
TRAJX(7-9)	$\ddot{x}, \ddot{y}, \ddot{z}$
TRAJX(10-15)	$\delta_1 x, \delta_1 y, \delta_1 z, \delta_1 \dot{x}, \delta_1 \dot{y}, \delta_1 \dot{z}$ first variation
TRAJX(16-21)	$\delta_2 x, \delta_2 y, \delta_2 z, \delta_2 \dot{x}, \delta_2 \dot{y}, \delta_2 \dot{z}$ second variation
. . .	
TRAJX(52-57)	$\delta_8 x, \delta_8 y, \delta_8 z, \delta_8 \dot{x}, \delta_8 \dot{y}, \delta_8 \dot{z}$ eighth variation
TCRASH	Set non-zero if impact occurs
FLVE	Non-zero to indicate predictor steps

2. Calling sequence

—

SUBROUTINES USED

A. Program

DAUX

COMMENTS

The integration list must be initialized before calling TRAJ. If impact occurs, the output is at the impact time, not TN. The initialization flag set non-zero externally, is returned zero by TRAJ.

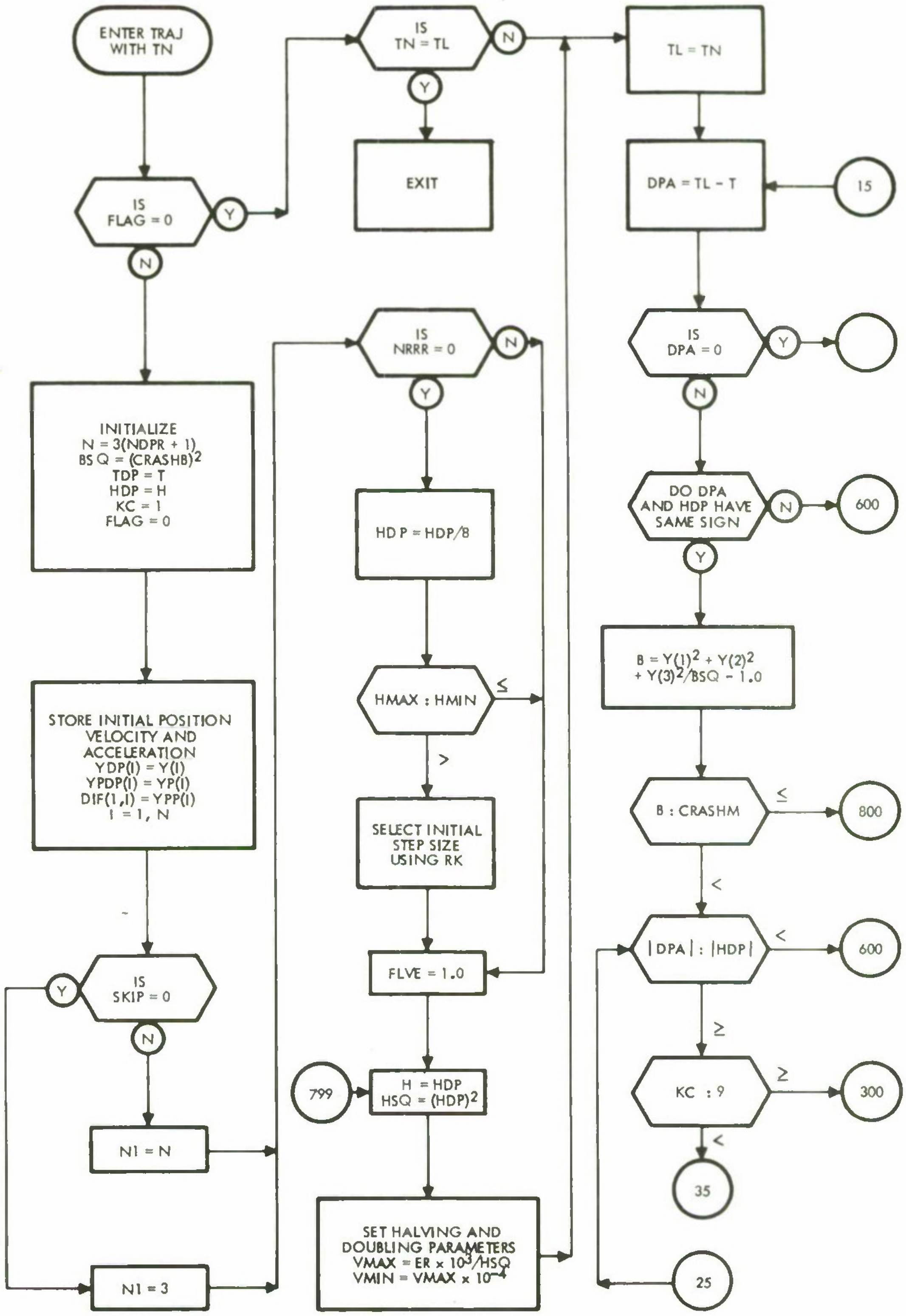


Figure 5-45. TRAJ Flow Diagram

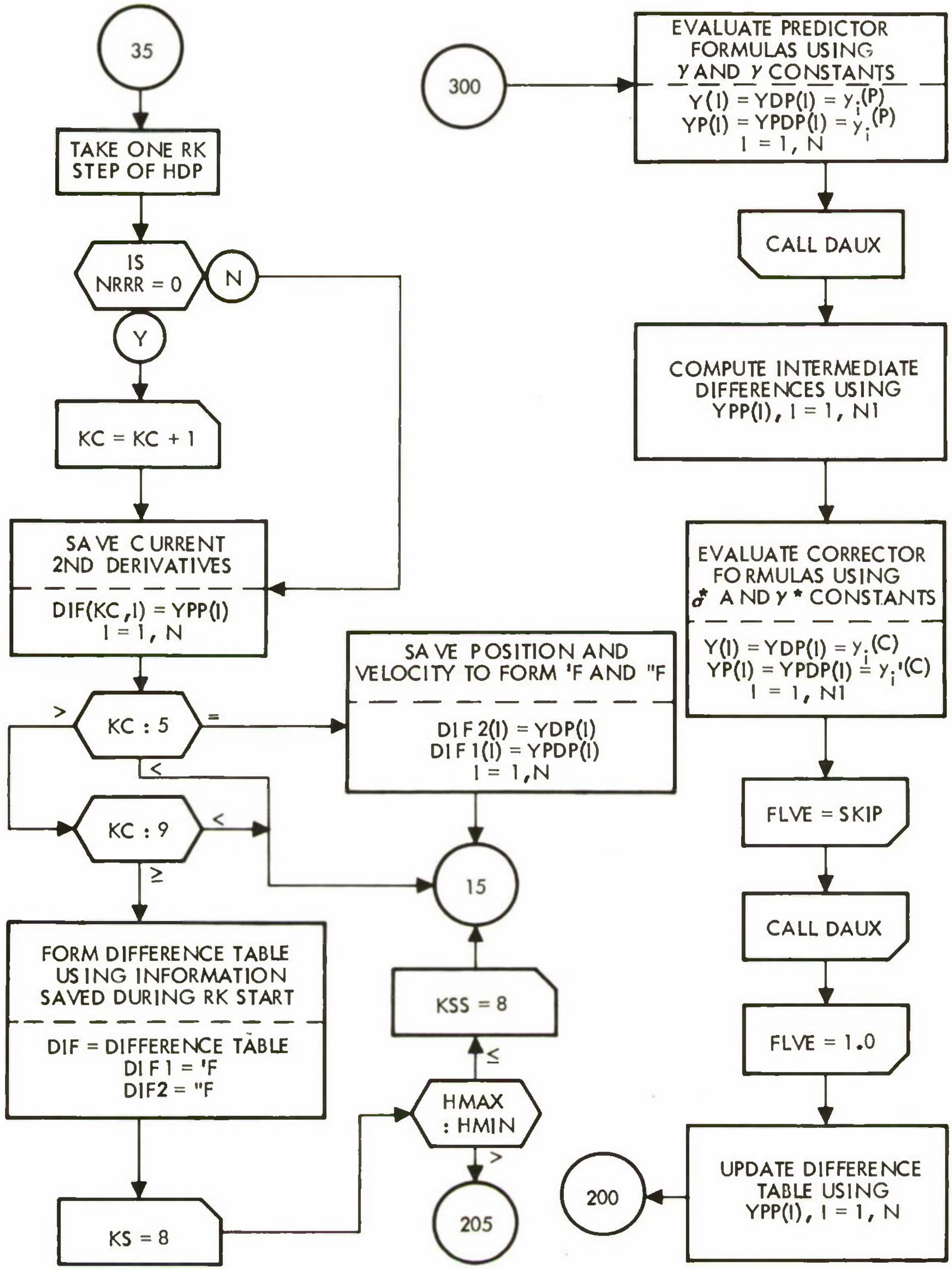


Figure 5-45. TRAJ Flow Diagram (Continued)

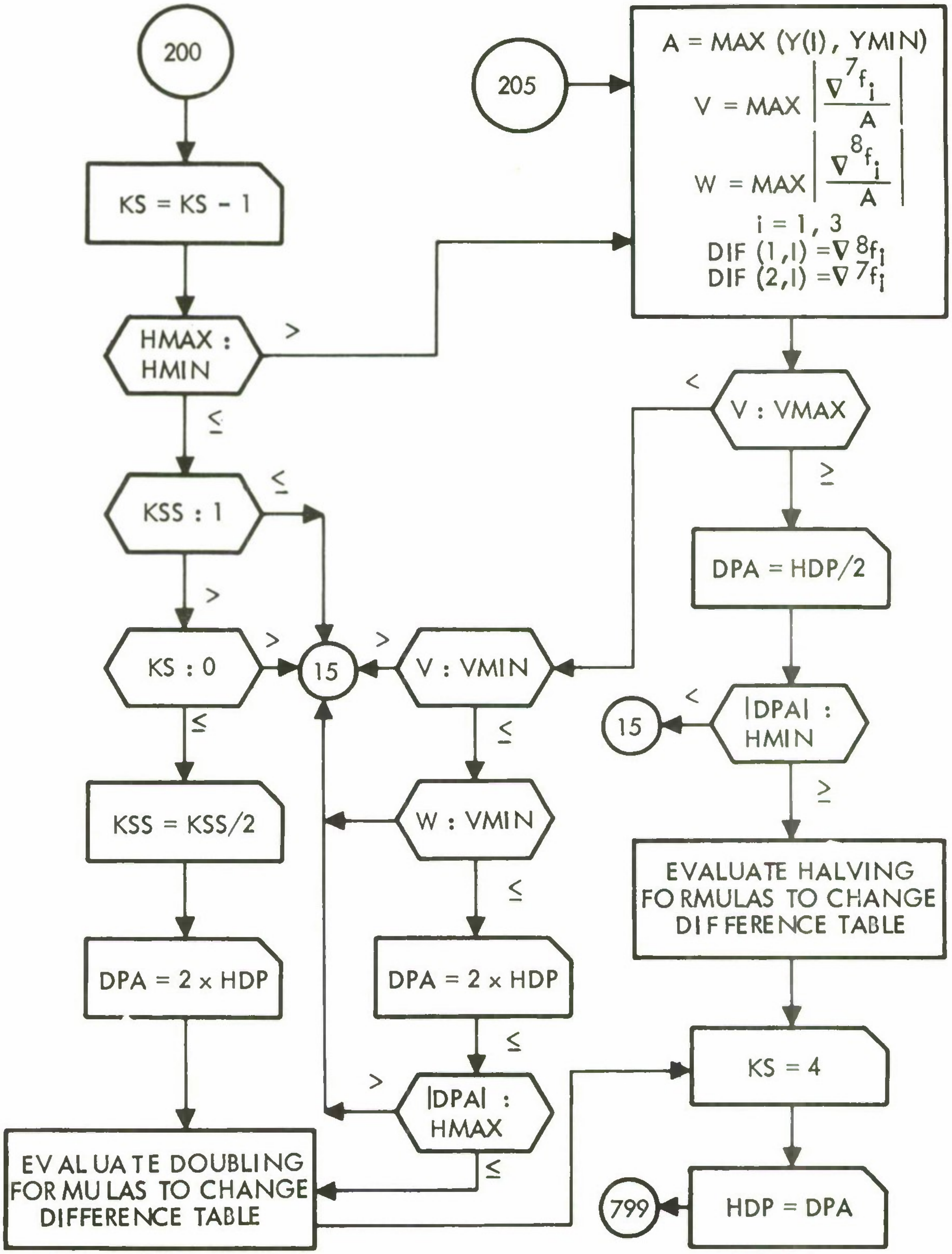


Figure 5-45. TRAJ Flow Diagram (Continued)

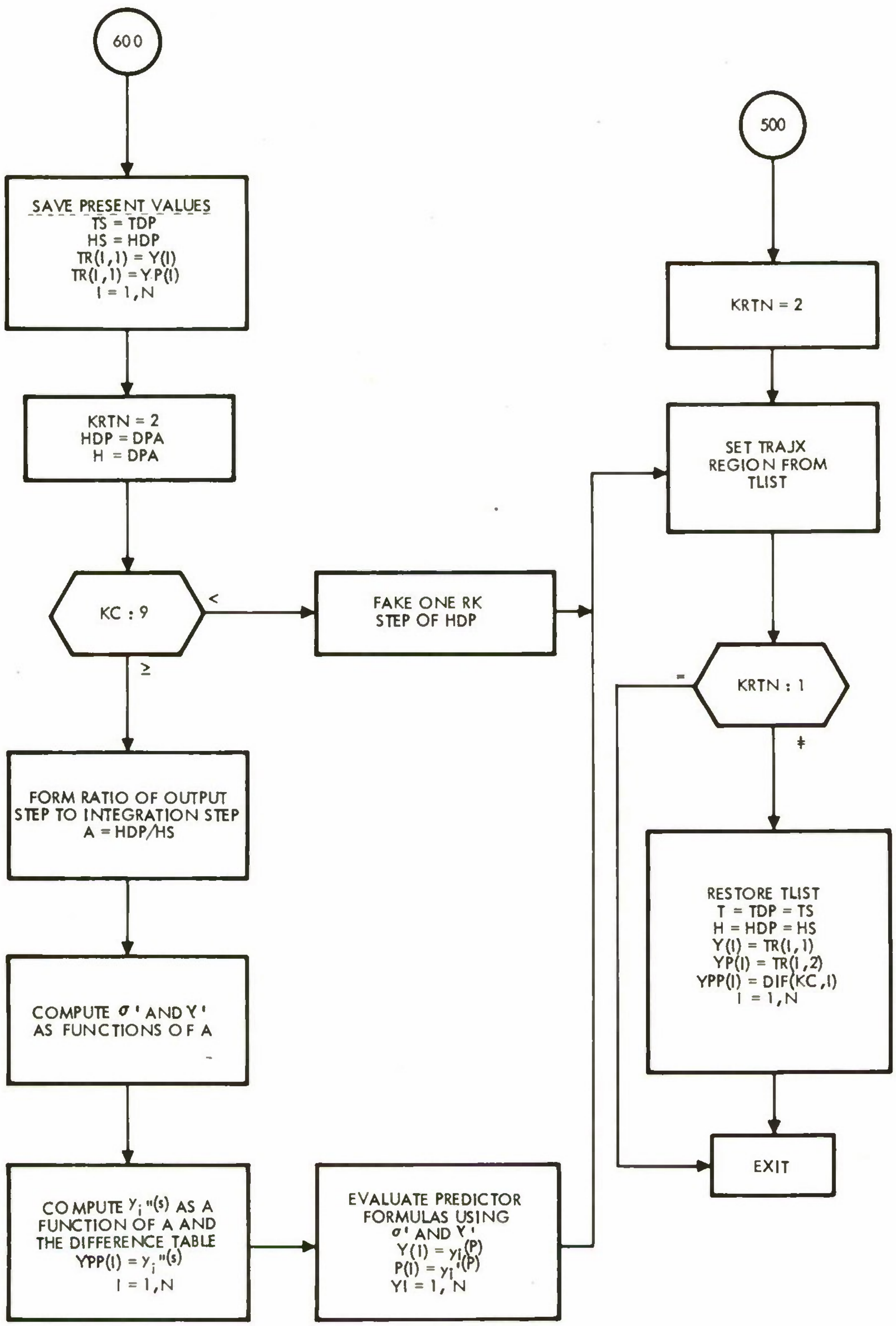


Figure 5-45. TRAJ Flow Diagram (Continued)

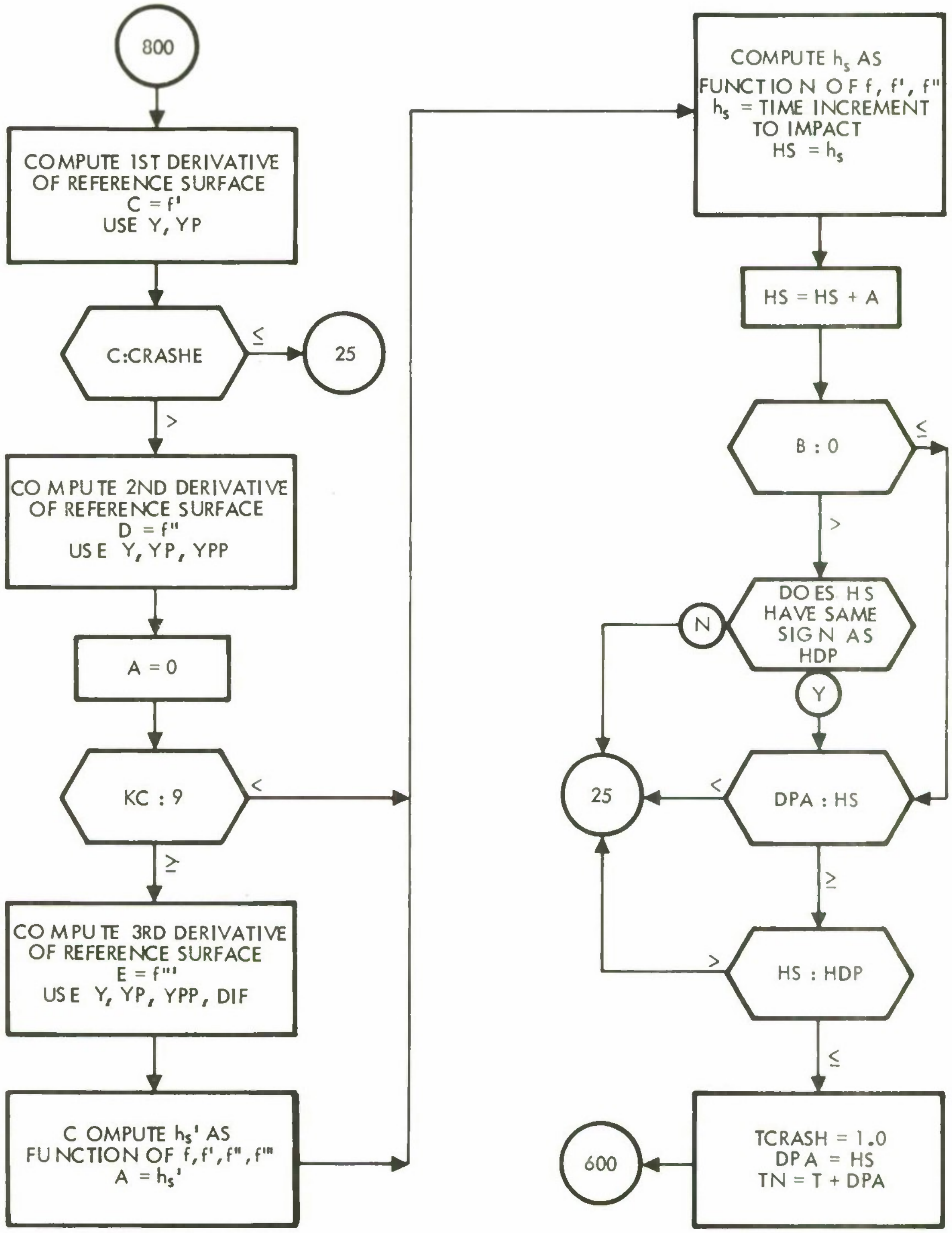


Figure 5-45. TRAJ Flow Diagram (Continued)

COMMON (TLIST) Storage

TLIST	Program Tag	Description			
1	FLAG	Initialization parameter—initialize when nonzero			
2	T	Current time			
3	H	Current step size			These values must be supplied when FLAG $\neq$ 0
4-30	Y(1-27)	$y_1, y_2, \ldots, y_n$			
31-57	YP(1-27)	$\dot{y}_1, \dot{y}_2, \ldots, \dot{y}_n$			
58-84	YPP(1-27)	$\ddot{y}_1, \ddot{y}_2, \ldots, \ddot{y}_n$	DAUX stores 2nd der.		
85-192	TR(1-27, 1-4)	Intermediate storage			N= 3(NDPR + 1)
193-489	DIF	Difference table		During Runge-Kutta phase	
	(1, 1-27)	$\nabla^8 f_i$		$\ddot{y}_{io}$	
	(2, 1-27)	$\nabla^7 f_i$	as I = 1, N	$\ddot{y}_{i1}$	as I = 1, N
	(3, 1-27)	$\nabla^6 f_i$		$\ddot{y}_{i2}$	
	(4, 1-27)	$\nabla^5 f_i$		$\ddot{y}_{i3}$	
	(5, 1-27)	$\nabla^4 f_i$	See method for description of this table.	$\ddot{y}_{i4}$	These values are saved during 8NR Runge Kutta steps.
	(6, 1-27)	$\nabla^3 f_i$		$\ddot{y}_{i5}$	
	(7, 1-27)	$\nabla^2 f_i$		$\ddot{y}_{i6}$	
	(8, 1-27)	$\nabla^1 f_i$		$\ddot{y}_{i7}$	
	(9, 1-27)	$f_i = y$		$\ddot{y}_{i8}$	
	(10, 1-27)	$'F_i$		y_{i4}	
	(11, 1-27)	$''F_i$		$\dot{y}_{i4}$	

SUBROUTINE IDENTIFICATION

A. Title

TRISE

B. Segment

PREMOD

C. Called by subroutine

PREMOD

FUNCTION

To search for and establish the time of rise for the current satellite relation to Millstone Hill (or whatever is the first station in the master sensor table VSTR(NSTAT)). The time for rise is assumed to occur when the elevation is $\geq -1.5^{\circ}$. The search is automatically terminated if rise does not occur within 60 minutes of the starting point (TB).

USAGE

A. Calling sequence

CALL TRISE

B. Input

1. COMMON

VSTR(NSTAT)	The coordinates and related quantities for the Millstone Hill radar.
TALFAG	Right ascension of Greenwich at 0 hours, day of epoch (radians).
TG	Initially, this is the time at TB, the time at which the trajectory is currently defined.
CDEG	Degrees per radian.
KOUT	Number of the output device.
TB	Time, in minutes from epoch, to initiate the search for rise. (Initially TB = TG).
TEPOCH	Time of epoch, minutes from 0 hours.

2. Calling sequence

—

C. Output

1. COMMON

TG	The time of rise, in minutes, from 0 hours day of epoch.

2. Calling sequence

—

D. Error/action messages

The program will take an error exit if either of the following messages are printed:

***NO RISE FOUND WITHIN 60 MINUTES OF TB.

***IMPACT OCCURRED WHILE SEARCHING FOR TRISE.

These messages are printed both on- and off-line.

E. Internal storage

TCRASH	Set non-zero by TRAJ if earth impact occurs.

The following items are transmitted internally between TRISE and PRELIM.

PSTAT	The working sensor table, preset with VSTR(NSTAT+1), VSTR(NSTAT+2),...., VSTR(NSTAT+9)
PUBS(2)	The current trajectory time
PVI(3)	Sin E where E = elevation

SUBROUTINE USED

A. Library

ASIN	.EXIT.
.FVIO.	.FWRD.
.FPRN.	.FFIL.

B. Program

TRAJ	Integrates equations of motion
PRELIM	Computes elevation and other observable quantities

EQUATIONS

—

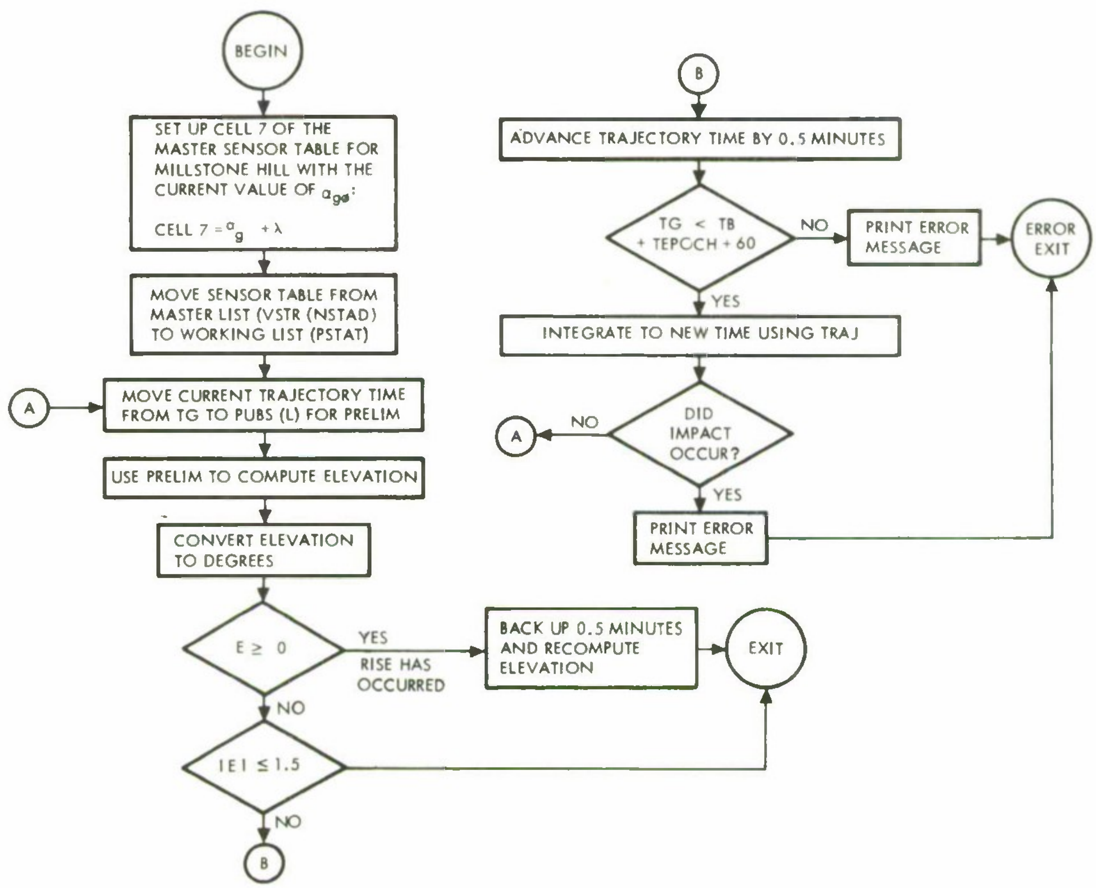


Figure 5-46. TRISE Flow Diagram

SUBROUTINE IDENTIFICATION

A. Title

TRJGEN

B. Segment

NRTPOD

C. Called by Subroutine

TRJGEN

FUNCTION

Driver for the trajectory link. Controls the logic associated with the trajectory integration and the generation of the trajectory tape.

USAGE

A. Calling Sequence

Call TRJGEN

B. Input

1. COMMON

KOUT	Output tape (print)
TEPOCH	Time of epoch, minutes from 0 hours
DTMAX	Maximum allowable time internal for an observation - in days since epoch
TUBSEF	Flag denoting when the last observation has been processed from tape. Set ≠ 0 when "end of file" encountered.
PLSTSN	Station ID for previous observation
TG	Integration time to go. Minutes from 0 hours, day of epoch
TCRASH	Flag indicating earth impact. Non-zero if inpact has occurred
KONTRL	Flag indicating mode of NRTPOD KONTRL = 1 Execute TRJGEN for curve fit and trajectory KONTRL = 2 Execute TRJGEN for trajectory only

2. Calling Sequence

—

C. Output

1. COMMON

—

2. Calling Sequence

—

D. Error/Action Messages

1. Action messages

"START TRAJECTORY"

and

"END TRAJECTORY"

Occur when the program begins executing the trajectory link and when execution of the trajectory link terminates

SUBROUTINES USED

A. Library

—

B. Program

SETIC	Initializes integration lists
SELECT	Selects next observation
PARSET	Sets up the PSTAT sensor information array from master sensor table for current observation
TRAJ	Integration subroutine
TRJTAP	Writes trajectory tape

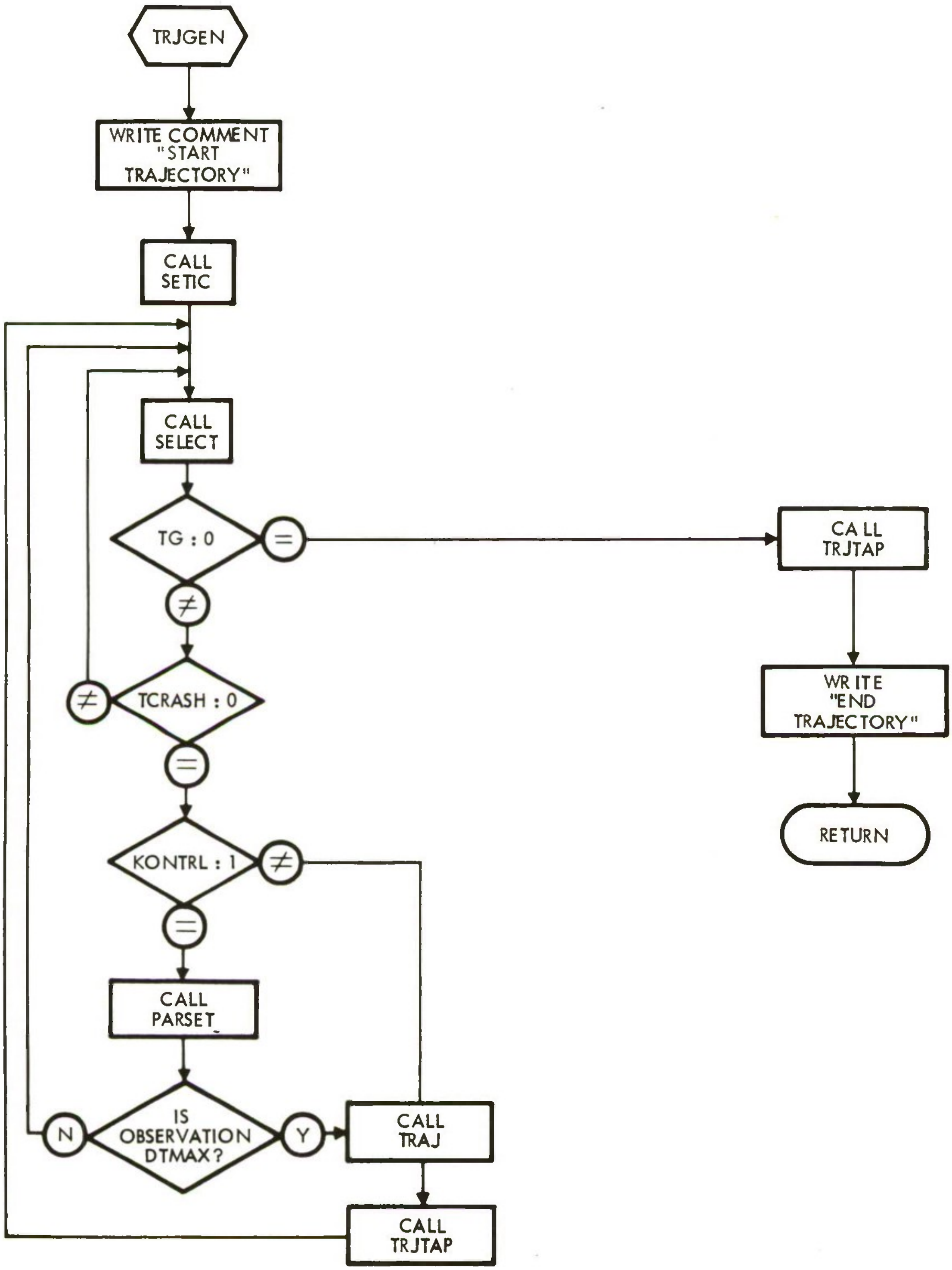


Figure 5-47. TRJGEN Flow Diagram

SUBROUTINE IDENTIFICATION

A. Title

TRJGET

B. Segment

NRTPOD partials - least square

C. Called by subroutine

DCITER

FUNCTION

TRJGET reads one trajectory record from the trajectory tape and, if necessary, sets the impact control flag.

USAGE

A. Calling sequence

Call TRJGET (TG)

B. Input

1. COMMON

ITRJTP	Trajectory tape number
TEPOCH	Minutes from midnight day of epoch to epoch

2. Calling sequence

TG	Observation time for which a corresponding trajectory record is to be read

3. Tape input

The trajectory tape generated by the trajectory segment

C. Output

COMMON

1. TRAJX (1 - 9) $(x, y, z, \dot{x}, \dot{y}, \dot{z}, \ddot{x}, \ddot{y}, \ddot{z})$

2. TRAJX $\left[10 + 6(i-1) \ldots 15 + 6(i-1)\right]$

$$\left(\frac{\partial x}{\partial p_i}, \frac{\partial y}{\partial p_i}, \frac{\partial z}{\partial p_i}, \frac{\partial \dot{x}}{\partial p_i}, \frac{\partial \dot{y}}{\partial p_i}, \frac{\partial \dot{z}}{\partial p_i}\right)$$

$i = 1, \ldots, NDPR; NDPR \leq 7$

		= -1, if impact is pre-epoch
3.	TCRASH	= 1, if impact is post-epoch
		= 0, if no impact

SUBROUTINES USED

A. Library

. FBLT.

. FRDB.

. FVIO.

SUBROUTINE IDENTIFICATION

A. Title

TRJPRO

B. Segment

NRTPOD

C. Called by Subroutine

NRTPOD

FUNCTION

Main driver controlling the coordination of all activities involving the three segments trajectory segment, curve fit segment, and the trajectory print and update segment.

USAGE

A. Calling Sequence

Call TRJPRO

B. Input

1. COMMON

KONTRL	Flag indicating mode of NRTPOD KONTRL = 1 Curve fit and trajectory = 2 Trajectory only
DCFLG	JDC card options (card column 41-50)
IFTEX	Exit flag from subroutine FIT IFTEX = 1 Solution has converged = 2 Maximum iterations exceeded and converging = 3 Failed K BOUNDS/8 = 4 Normal return = 5 Maximum iterations exceeded and converging
PSTFLG	IDC options (card columns 51-60)

2. Calling Sequence

—

C. Output

1. COMMON

—

2. Calling Sequence

—

D. Error/Action Messages

SUBROUTINES USED

A. Library

—

B. Program

TPRLM	Performs necessary initialization prior to a differential correction pass
TRJGEN	Driver for the trajectory segment; generates the trajectory tape
DCITER	Driver for the curve fit segment
PRUDRV	Trajectory print and update driver

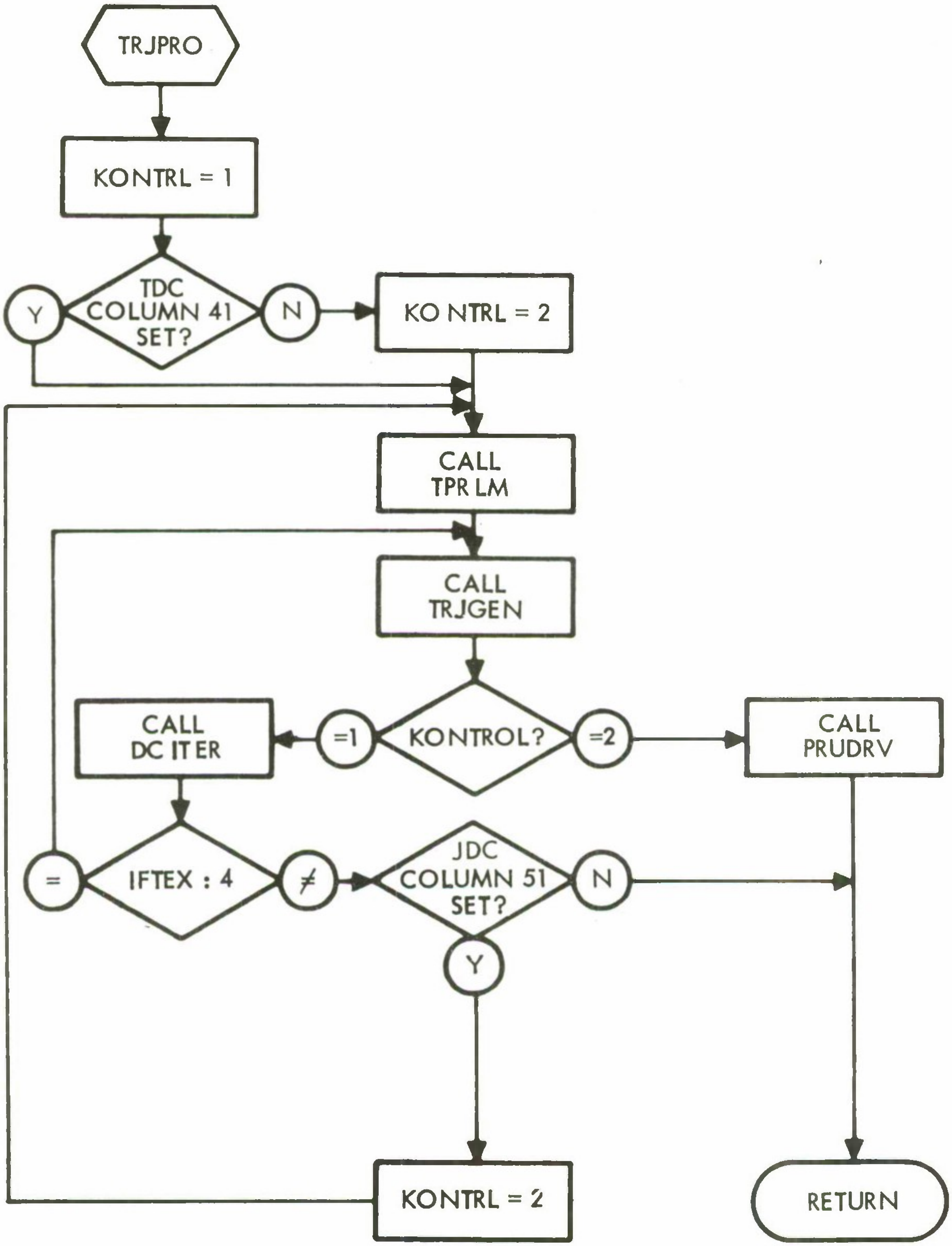


Figure 5-48. TRJPRO Flow Diagram

SUBROUTINE IDENTIFICATION

A. Title

TRJTAP

B. Segment

NRTPOD

C. Called by Subroutine

TRJGEN

FUNCTION

Function is to write the trajectory tape used by the curve fit and trajectory print and update segments.

USAGE

A. Calling Sequence

Call TRJTAP

B. Input

1. COMMON

ITRJTP	Trajectory tape number
TG	Integration time to go ... minutes from 0 hours day of epoch
TRAJX	Integration coordinates at time TG: position, velocity, acceleration, partials of position and velocity w. r. t. the category 1 variables
TCRASH	Impact flag - non-zero if impact has occurred

2. Calling Sequence

IOPT	Flag indicating type of trajectory record written on trajectory tape IOPT = 1 Writes a standard data record = 2 Writes a pseudo "end of file" record

C. Output

1. COMMON

—

2. Calling Sequence

—

TRJTAP

D. Error/Action Messages

SUBROUTINES USED

A. Library

—

B. Program

—

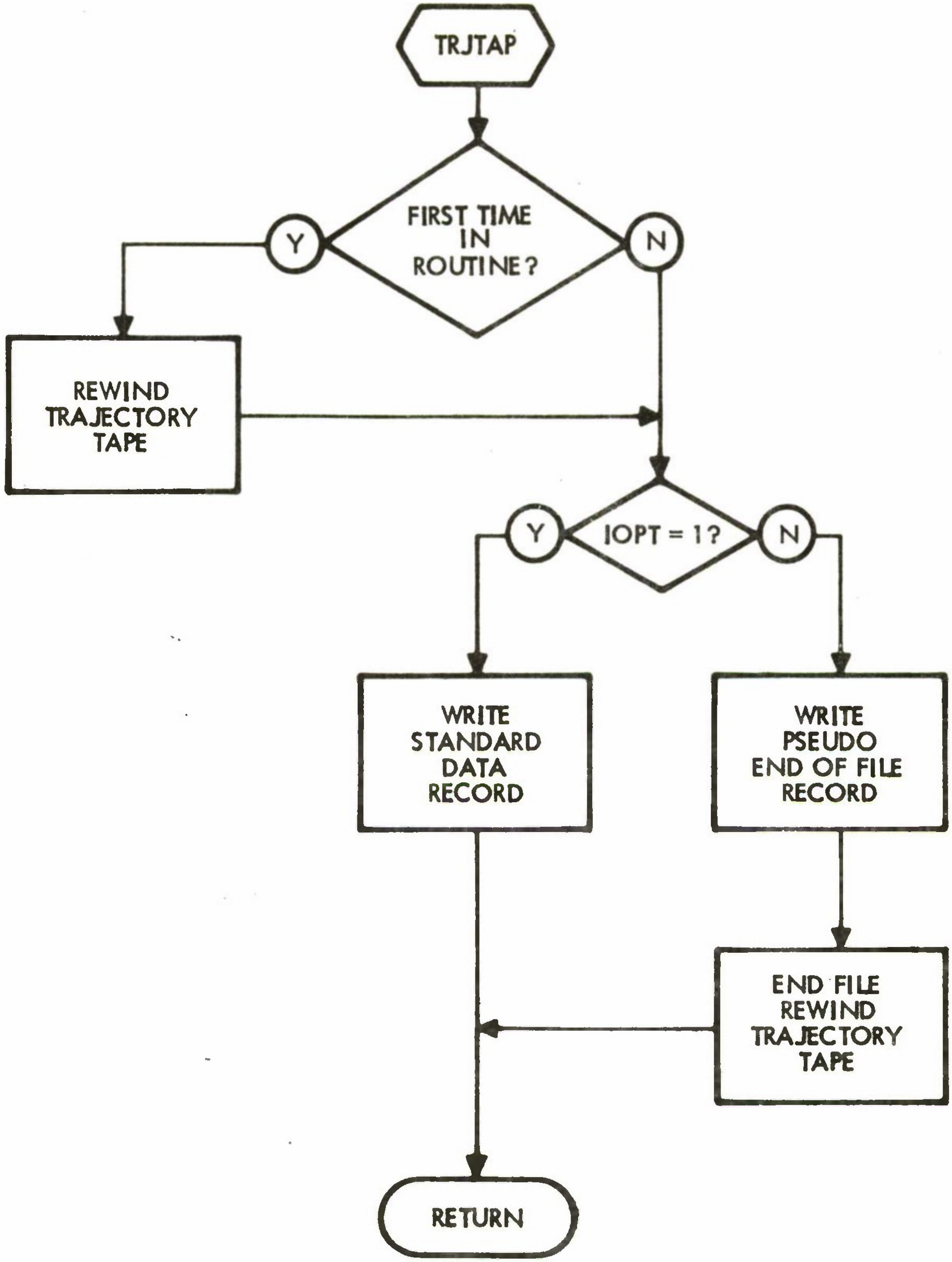


Figure 5-49. TRJTAP Flow Diagram

SUBROUTINE IDENTIFICATION

A. Title

TSET

B. Segment

PREMOD

C. Called by subroutine

PREMOD

FUNCTION

To establish TNODE, the final time of interest for the core ephemeris. TNODE will be the smallest of:

a) The time for set for this satellite relative to Millstone Hill. (Set is defined as elevation ≤ -1.5°)

b) TEPOCH + 60 minutes

c) TEPOCH+TF, the maximum time to be considered for the core ephemeris

USAGE

A. Calling sequence

CALL TSET

B. Input

1. COMMON

VSTR(NSTAT)	The first entry in the master sensor table, assumed to be Millstone Hill.
TG	Upon entrance, the current integration time. This should be the value of MHESPOD epoch.
TEPOCH	Epoch time, minutes from midnite.
TF	The final time to be considered for the core ephemeris, in minutes from epoch.
CDEG	Degrees per radian.
KOUT	Number of the output device.

2. Calling sequence

—

C. Output

1. COMMON

TNODE	The final time of interest for the core ephemeris, in minutes from 0 hours day of epoch.

2. Calling sequence

—

D. Error/action messages

The program will take an error exit if the following message is printed:

***IMPACT OCCURRED WHILE SEARCHING FOR TSET.

This message is printed both on- and off-line.

E. Internal storage

TCRASH	Set non-zero by TRAJ if earth impact occurs.

The following items are used in the PRELIM interface.

PUBS(2)	Trajectory time at which elevation is desired
PSTAT	Working sensor table; contains VSTR (NSTAT+1) through VSTR(NSTAT+9)
PVI(3)	Sin E, where E = elevation

SUBROUTINES USED

A. Library

ASIN	.EXIT.
.FVIO.	.FWRD.
.FPRN.	.FFIL.

B. Program

TRAJ	Integrates equations of motion
PRELIM	Calculates elevation angle

EQUATIONS

—

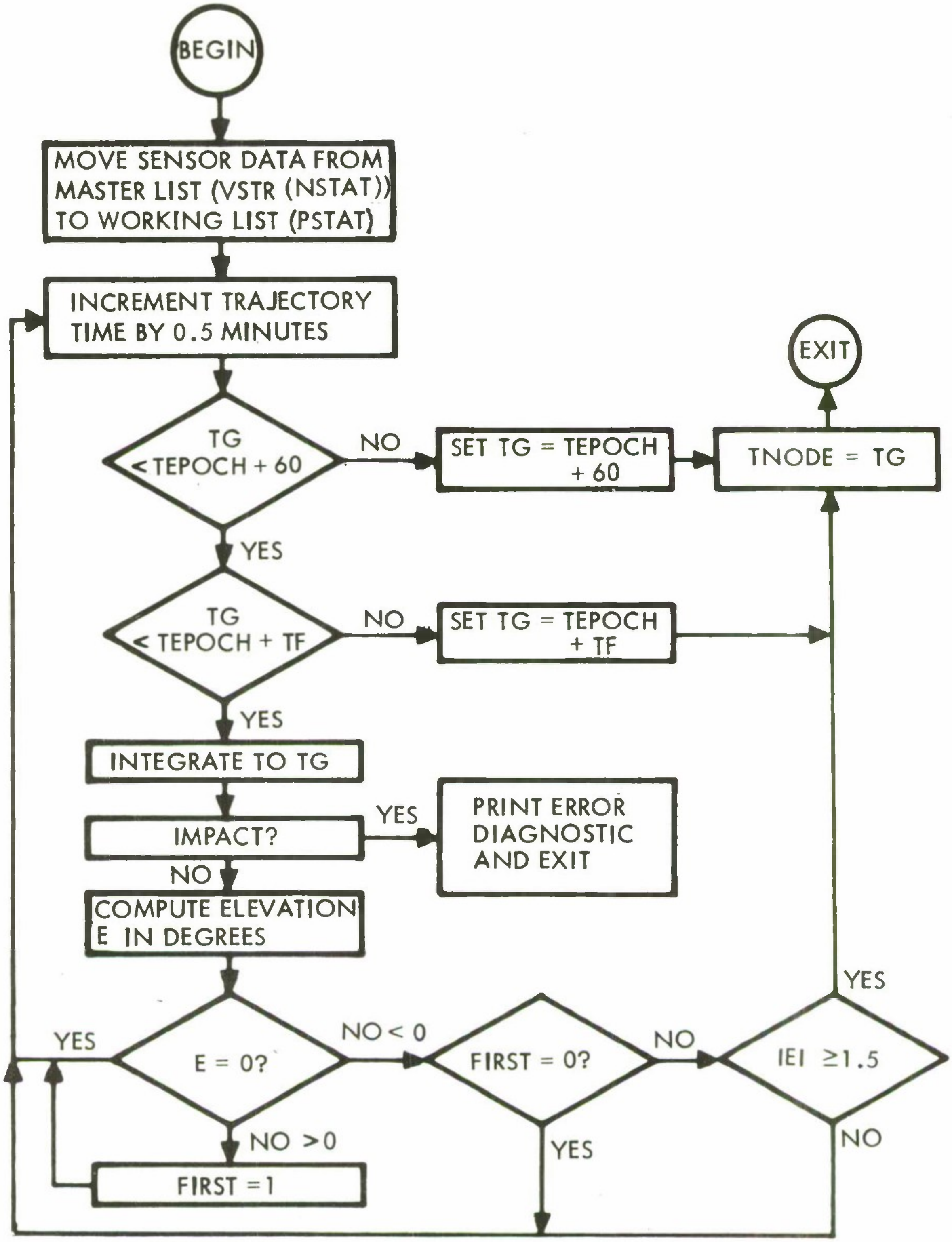


Figure 5-50. TSET Flow Diagram

SUBROUTINE IDENTIFICATION

A. Title

UBSGET

B. Segment

MHESPØD

C. Called by subroutine

SELECT

FUNCTION

Function is to get next observation time from variable storage.

USAGE

A. Calling sequence

Call UBSGET

B. Input

1. CØMMØN

DBUFS	Auxiliary buffer storage
VSTR (NSTAT)	The starting location of the table of observations
TEMP	Temporary storage
TUBSEF	Sentinel block detection flag
IPFRST	0 to indicate first time in RADR
KBCT	Logical tape number for BCT tape
NDAPØB	Number of DAP observations
NITCT	Iteration counter
NØØBS	Number of pre-epoch observations on BCT tape
NSTAT	Station ID associated with DAP observations
SIGMH	Standard deviations of DAP observations

2. Calling sequence

—

C. Output

1. CØMMØN

PUBS(1) Sensor number
(2) Time in min from 0^h day of epoch
(3) Range measurement
(4) Azimuth measurement
(5) Elevation measurement

$$\begin{array}{ll} \text{PSIG (1)} & \\ (2) & \\ (3) & \\ (4) & \end{array} \left.\begin{array}{l} \sigma_R \\ \sigma_A \\ \sigma_E \\ \sigma_{RDT} \end{array}\right\} \text{Observation weights}$$

2. Calling sequence

—

SUBROUTINES USED

A. Library

SQRT

B. Program

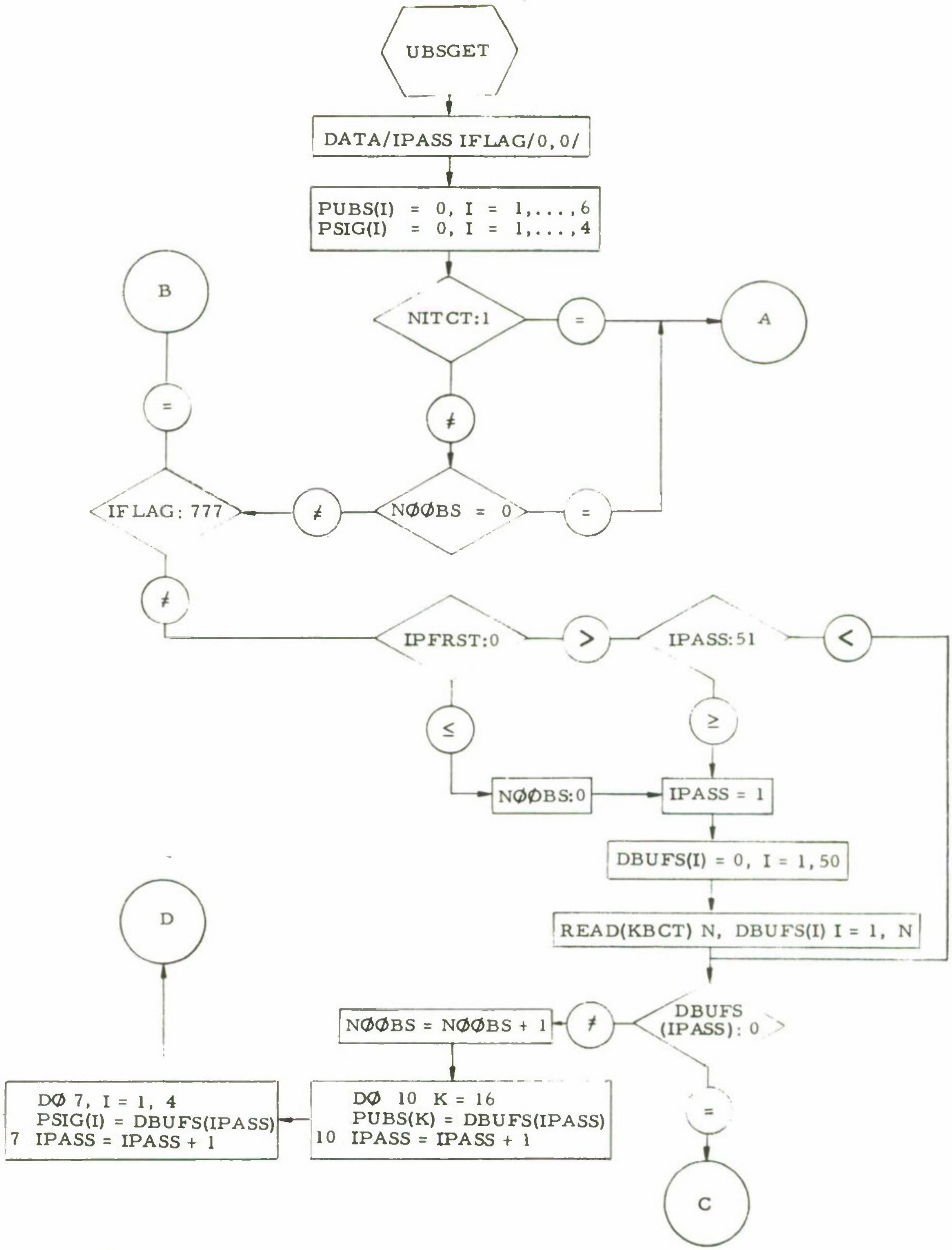


Figure 5-51. UBSGET Flow Diagram

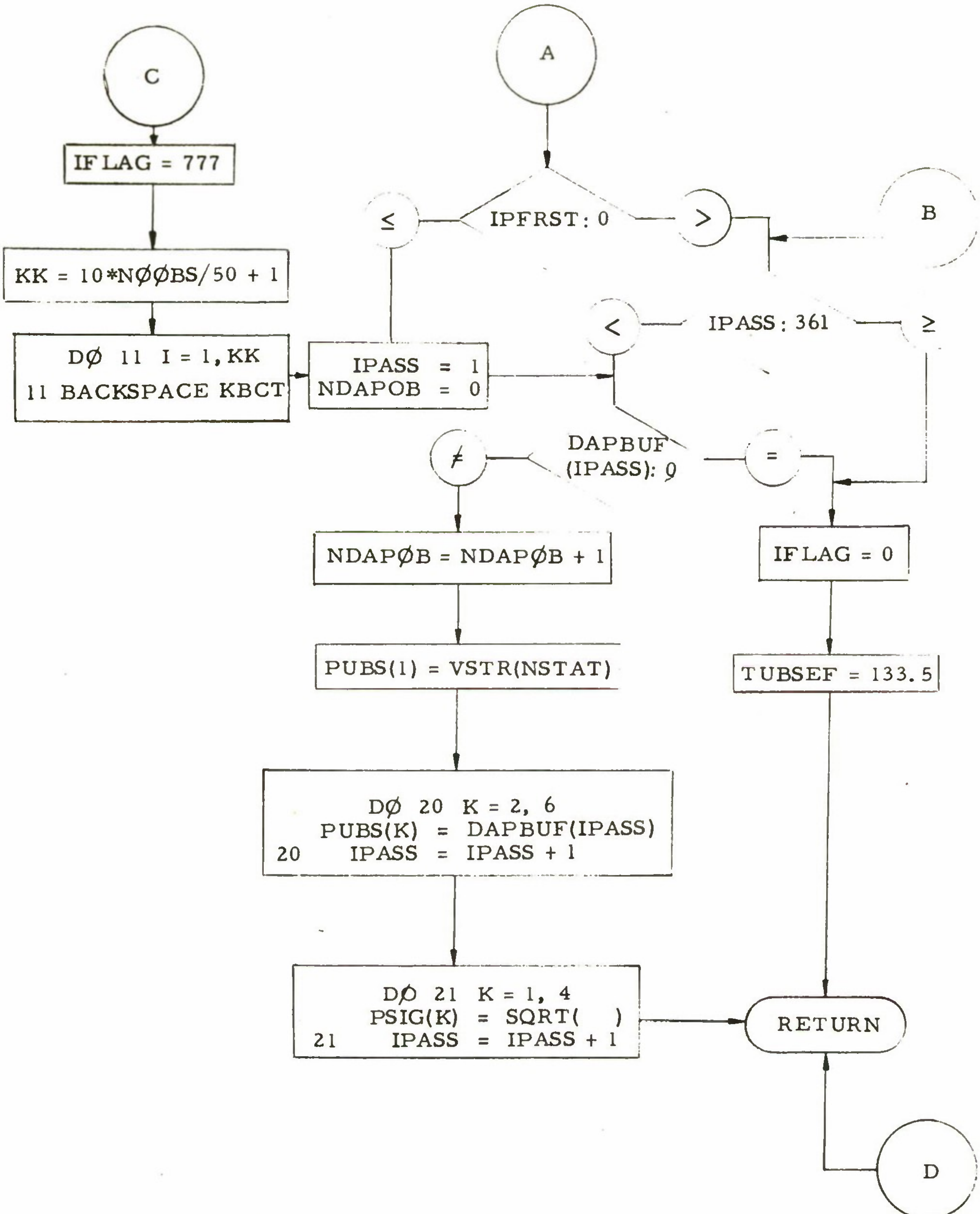


Figure 5-51. UBSGET Flow Diagram (Continued)

SUBROUTINE IDENTIFICATION

A. Title

UBSGET

B. Program

NRTPOD

C. Called by subroutines

DCITER

SELECT

FUNCTION

To process the observation tape. The observation data are moved into VSTR, from VSTR(NUBS) to VSTR (COMLST).

USAGE

A. Calling Sequence

Call UBSCET

B. Input

1. COMMON

COMLST	The last cell of VSTR
MT	The observation tape number
NUBS	The start of the observation storage in VSTR

2. Calling Sequence

—

C. Output

1. COMMON

PUBS	The next observation to be processed
	PUBS(1). . . Station ID
	(2). . . Time (minutes from 0 hours day of epoch)
	(3). . . Range (earth radii)
	(4). . . Azimuth (radians)
	(5). . . Elevation (radians)
	(6). . . Range rate (earth radii/minute)
	(7). . . Not used
TUBSEF	Set non-zero when all observations have been processed

2. Calling Sequence

—

D. Error/Action Messages

—

E. Internal Storage

1. COMMON

BYPASS	First time in flag, assumed initially 0, set to 133.5 following the initial entrance
IFLAG	End of tape indicator, assumed initially 0, set to 777 when the last record of the observation tape has been moved to VSTR
SKIPC	Not used

2. Internal

J	A pointer in VSTR, internally incremented to indicate the next observation from VSTR to be processed

SUBROUTINES USED

A. Library

—

B. Program

MOVEVS	Moves a 7 cell observation from VSTR to PUBS

EQUATIONS

—

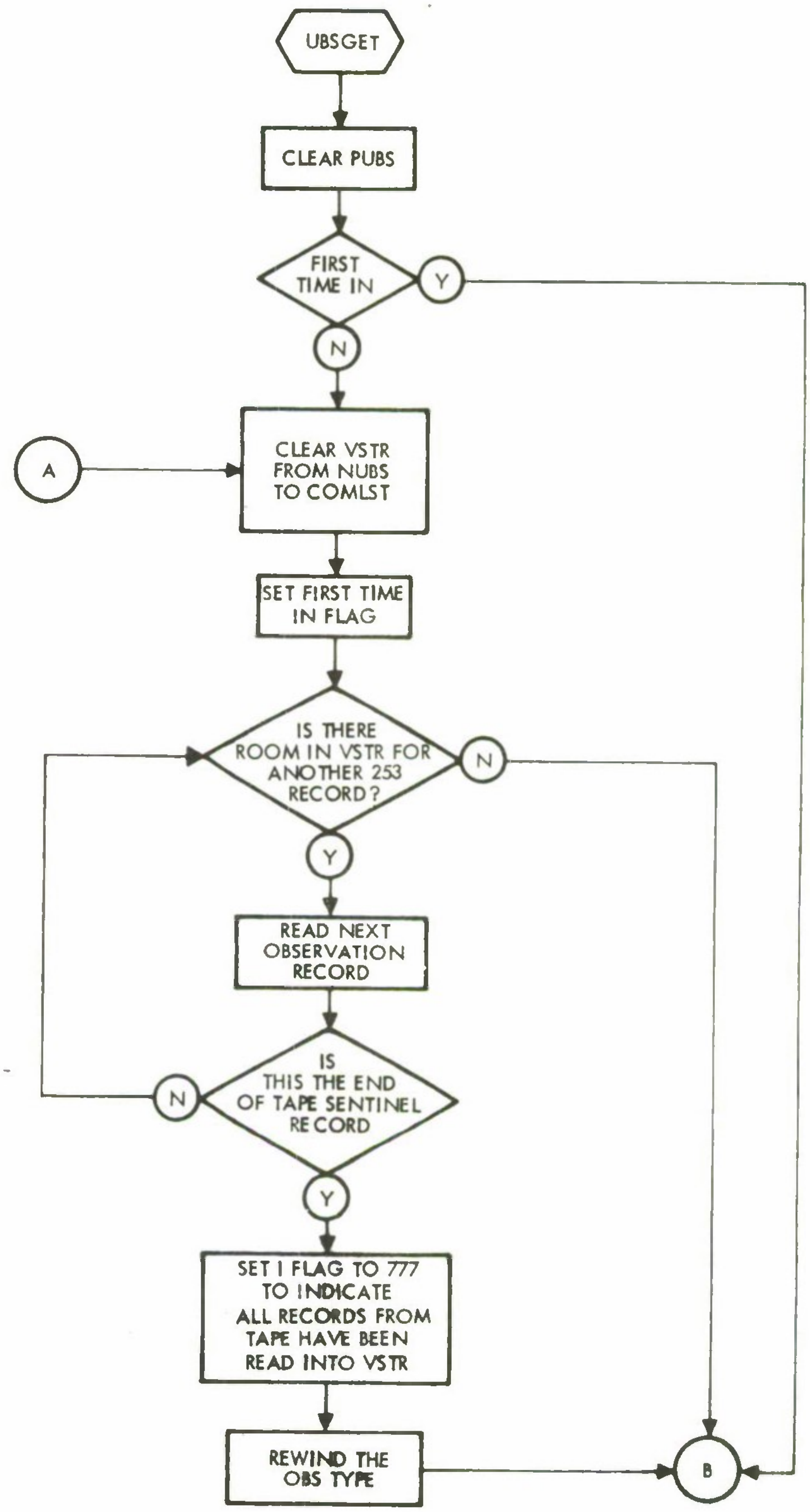


Figure 5-52. UBSGET Flow Diagram

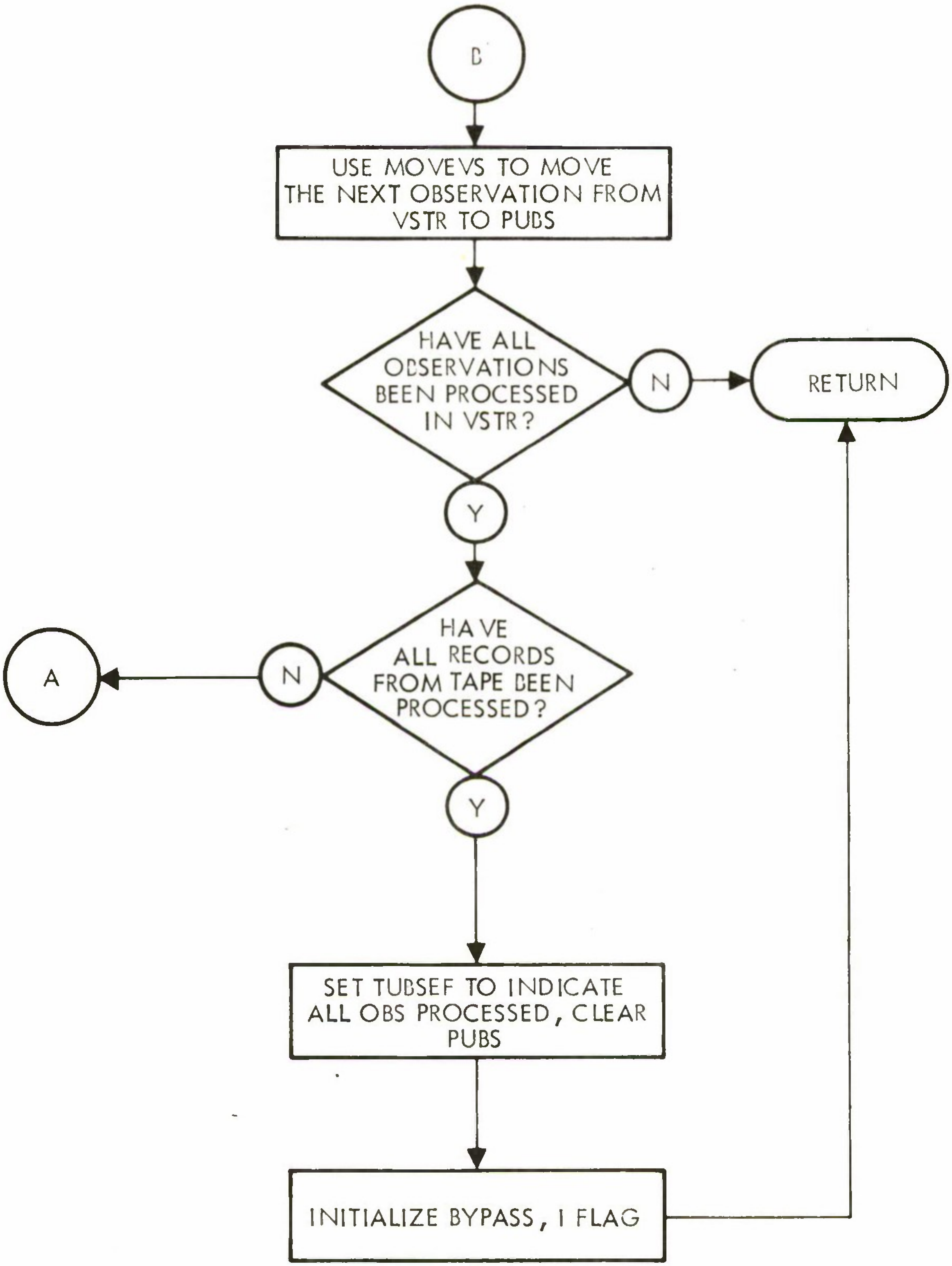


Figure 5-52. UBSGET Flow Diagram (Continued)

SUBROUTINE IDENTIFICATION

A. Title
UPDATE

B. Segment
PREMOD

C. Called by subroutine
PREMOD

FUNCTION

To update an a priori normal matrix (A^TA) to the MHESPOD epoch. This routine assumes that the variational equations for $x, y, z, \dot{x}, \dot{y}, \dot{z}$, have been integrated from the given epoch of A^TA to the desired epoch and that

$$\text{TRAJX (1-6)} = \frac{\partial x_t}{\partial x_o} \frac{\partial y_t}{\partial x_o} \cdots \frac{\partial \dot{z}_t}{\partial x_o}$$

$$\text{TRAJX (7-12)} = \frac{\partial x_t}{\partial y_o} \frac{\partial y_t}{\partial y_o} \cdots \frac{\partial \dot{z}_t}{\partial y_o}$$

$$\vdots \qquad \vdots \quad \vdots \qquad \vdots$$

$$\text{TRAJX (31-36)} = \frac{\partial x_t}{\partial \dot{z}_o} \frac{\partial y_t}{\partial \dot{z}_o} \cdots \frac{\partial \dot{z}_t}{\partial \dot{z}_o}$$

subscript o $\Rightarrow$ input epoch

subscript t $\Rightarrow$ desired epoch

USAGE

A. Calling sequence
CALL UPDATE

B. Input

1. COMMON

SMAT (1-21)	The a priori normal matrix stored upper triangular by rows in units of minutes. The rows and columns are assumed in the order of $x, y, z, \dot{x}, \dot{y}, \dot{z}$.

TRAJX (1-36)	The state transition matrix describing the partial of Cartesion position and velocity at the desired update time with respect to the given epoch of A^TA. (See FUNCTION) units of minutes.
KOUT	Number of the output device.

2. Calling sequence

—

C. Output

1. COMMON

VSTR(NATA)	The updated A^TA matrix stored upper triangular by rows, and augmented with a 0 column vector corresponding to A^Tb:

if a_{ij} = updated A^TA

VSTR(NATA)...VSTR(NATA+6) = $a_{11}, a_{12}, a_{13}, \ldots a_{16}, 0$

VSTR(NATA+7)... VSTR(NATA+12) = $a_{22}, a_{23}, \ldots a_{26}, 0$

$\vdots$

VSTR(NATA+25), VSTR(NATA+26) $a_{66}, 0$

2. Calling sequence

—

D. Error/action messages

—

E. Internal storage

A (6, 6)	Holds the transpose of TRAJX (1-36)
B (6, 6)	The inverse of A (6, 6)
C (6, 6)	The transpose of B (6, 6)
D (1-21)	The contents of SMAT stored lower triangular by rows
E (1-21)	The updated normal matrix stored lower triangular by rows. (See equations)

SUBROUTINES USED

A. Library

—

B. Program

MABAT	Triple matrix product routine
JCBINV	Computes the inverse of a state transition partials matrix.

EQUATIONS

$$(A^T A)_t = \left[\left(\frac{\partial x_t}{\partial x_o}\right)^t\right]^{-1} (A^t A)_o \left[\frac{\partial x_t}{\partial x_o}\right]^{-1}$$

SUBROUTINE IDENTIFICATION

A. Title

UVECT

B. Segment

MHESPØD

PREMØD

C. Called by subroutines

RPRESS

FUNCTION

Function is to unitize a three-dimenional vector.

USAGE

A. Calling sequence

CALL UVECT (A(I), B, C)

B. Input

1. CØMMØN

—

2. Calling sequence

A	Name of array containing the vector
I	Subscript locating x component of desired vector in A

C. Output

1. CØMMØN

—

2. Calling sequence

B	Name of array containing unitized vector
C	Magnitude of original vector A

D. Error/action messages

—

SUBROUTINES USED

A. Library

SORT

B. Program

—

EQUATIONS

$C = |\bar{A}|$

$\bar{B} = \bar{A}/C$

SUBROUTINE IDENTIFICATION

A. Title

VAREQ

B. Segment

MHESPOD
PREMOD
NRTPOD

C. Called by subroutine

DAUX

FUNCTION

Function is to account for the central body and J_2 effects and to evaluate the second derivatives for the variational equations.

USAGE

A. Calling sequence

Call VAREQ

B. Input

1. COMMON

CMU	GM of Earth
TR2	Magnitude squared of the radius vector from the center of the Earth to the vehicle
TR3	Magnitude cubed of the above vector
TR5	Magnitude to the fifth power of the above vector
TLIST	Numerical integration working storage
PMAT	Matrix of position dependent effects in the variational equations
VMAT	Matrix of velocity dependent effects in the variational equations
FJ	Array containing the desired zonal harmonic constants (J_1, J_2, $\cdots$, J_{12})
NDPR	Number of Category 1 variables being solved for

$$\text{PMAT} = \text{PMAT} + \begin{bmatrix} x^2S - U & xyS & xzT \\ xyS & y^2S - U & yzT \\ xzT & yzT & z^2T - 3U \end{bmatrix}$$

$$\frac{d^2}{dt^2}\left(\frac{\partial \vec{x}}{\partial p_i}\right) = \text{PMAT}\left(\frac{\partial \vec{x}}{\partial p_i}\right) + \text{VMAT}\left(\frac{\partial \dot{\vec{x}}}{\partial p_i}\right) \qquad i = 1, 2, \cdots, \text{NDPR}$$

where

$$\frac{\partial \vec{x}}{\partial p_i} = \left[\frac{\partial x}{\partial p_i}, \frac{\partial y}{\partial p_i}, \frac{\partial z}{\partial p_i}\right]$$

SUBROUTINE IDENTIFICATION

A. Title

VPERT

B. Segment

MHESPØD

PREMØD

C. Called by subroutines

SETIC

FUNCTION

Function is to compute the partials of the Cartesian coordinates with respect to desired Category 1 parameters and to initialize the integration list with these partials.

USAGE

A. Calling sequence

Call VPERT

B. Input

1. CØMMØN

2. Calling sequence

—

C. Output

1. CØMMØN

TLIST Numerical integration working storage

2. Calling sequence

—

D. Error/action messages

SUBROUTINES USED

A. Library

CØSF
SINF

B. Program

—

EQUATIONS

Initialize variational equations.

$$\begin{pmatrix} \frac{\partial x}{\partial x} & \frac{\partial y}{\partial x} & \frac{\partial z}{\partial x} & \frac{\partial \dot{x}}{\partial x} & \frac{\partial \dot{y}}{\partial x} & \frac{\partial \dot{z}}{\partial x} \\ \frac{\partial x}{\partial y} & & & & & \\ \cdot & & & & & \\ \cdot & & & & & \\ \cdot & & & & & \\ \frac{\partial x}{\partial \dot{z}} & - & - & - & - & \frac{\partial \dot{z}}{\partial \dot{z}} \end{pmatrix} = \begin{pmatrix} 1 & & & & & \\ & 1 & & & 0 & \\ & & 1 & & & \\ & 0 & & 1 & & \\ & & & & 1 & \\ & & & & & 1 \end{pmatrix}$$

SUBROUTINE IDENTIFICATION

A. Title
WEOFT

B. Segment
NRTPOD - Input Processor

C. Called by subroutine
LODOBS

FUNCTION

Function is to write a terminal record of 1.0's on the NRTPOD observation tape. The record size is 253 words.

USAGE

A. Calling sequence
Call WEOFT

B. Input

1. Blank COMMON
   MT Symbolic observation tape

2. Labeled COMMON
   —

3. Calling sequence
   —

C. Output

1. COMMON
   —

2. Calling sequence
   —

D. Error/action messages

SUBROUTINES USED

A. Library
—

B. Program
—

SUBROUTINE IDENTIFICATION

A. Title

WRTCOM

B. Segment

PREMOD

C. Called by subroutine

WRTCOM

FUNCTION

Write the MESCOM common record on the BCT tape.

USAGE

A. Calling sequence

CALL WRTCOM

B. Input

1. COMMON

KBCT	Logical tape number of the BCT

2. Calling sequence

—

C. Output

None

A 900-word binary record is written on the BCT

D. Error/action messages

—

SUBROUTINES USED

A. Library

.FVIO. .FBLT.
.FWRB. .FWLR.

B. Program

—

EQUATIONS

—

SUBROUTINE IDENTIFICATION

A. Title

WRTOBS

B. Segment

NRTPOD - Input processor

C. Called by subroutine

LODOBS

FUNCTION

Function is to write observations on the observations tape in blocks. The block size is a full 253 word record.

USAGE

A. Calling sequence

Call WRTOBS (STORE)

B. Input

1. COMMON

MT	Symbolic observations tape
NMBER	Total number of observations to be written on the observation tape

2. Calling sequence

STORE	Starting location of the observations array to be written on tape

C. Output

1. COMMON

—

2. Calling sequence

—

D. Error/action messages

—

SUBROUTINES USED

A. Library

—

B. Program

—

6. COORDINATE SYSTEMS

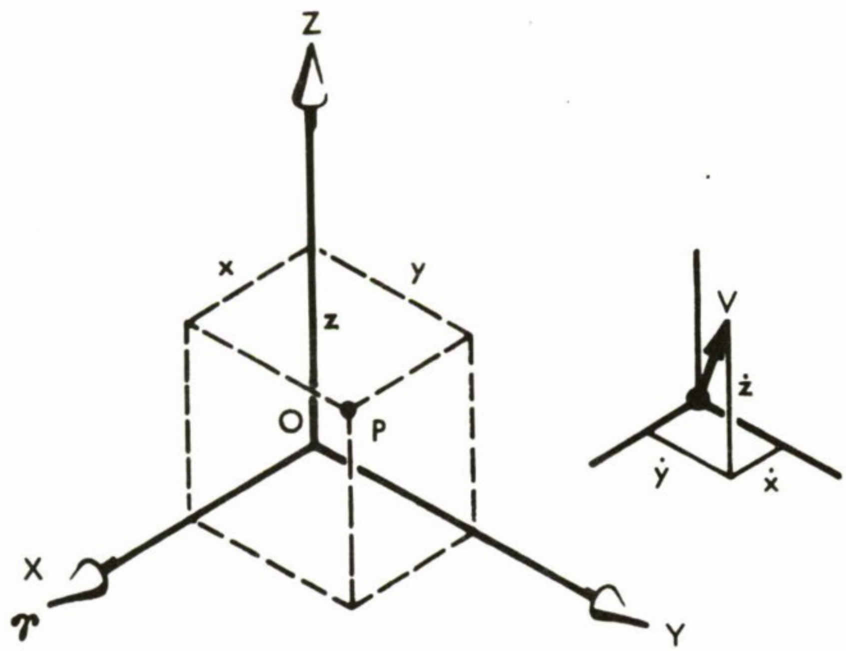
This section describes and illustrates the various coordinate systems used by PREMOD-MHESPOD and NRTPOD either in receiving or in presenting the results.

The following are definitions of terms applicable to the different coordinate systems:

Vernal Equinox:	That point of intersection of the ecliptic and celestial equator where the sun crosses the equator from south to north in its apparent annual motion along the ecliptic
Equator:	The great circle intersection of the celestial sphere and a plane containing the center of mass perpendicular to the rotating axis of the earth
True of (Epoch or Date)	The actual position at a given time of the vernal equinox including both precession and nutation
Mean of (Epoch or Date)	A fictitious equinox whose position is that of the vernal equinox at a particular time with the effect of a nutation removed
Osculating Elements:	The elements of an instantaneous orbit which are tangent to the actual trajectory, having the same position and velocity at that time
Date:	An exact time; e.g., the date of an observation is the exact time at which it was made
Epoch:	Some initial reference instant of time

6.1 EARTH CENTERED INERTIAL CARTESIAN SYSTEM

The position and velocity of a body at point P are $P = P(x, y, z, \dot{x}, \dot{y}, \dot{z})$.



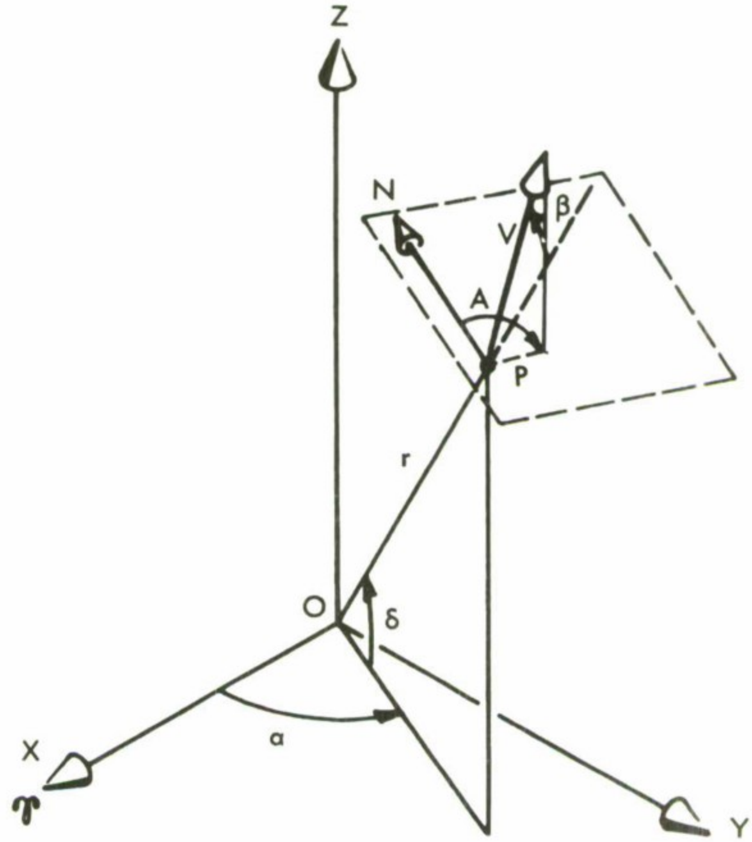
where

- O is the geocenter
- V is the velocity vector
- X is a vector from O in the equatorial plane directed to the true vernal equinox at 0.0h universal time on the day of epoch
- Y is a vector from O and perpendicular to X such that (X, Y, Z) is a right-handed system
- Z is a vector perpendicular to the equatorial plane and directed north.

In $P = P(x, y, z, \dot{x}, \dot{y}, \dot{z})$, x, y, z are components of position of the body in the X, Y, Z directions respectively, and $\dot{x}, \dot{y}, \dot{z}$ are its components of velocity in these directions.

6.2 GEOCENTRIC POLAR SPHERICAL (ADBARV) SYSTEM

The position and velocity of a body at point P are P = P(α, δ, β, A, r, v)



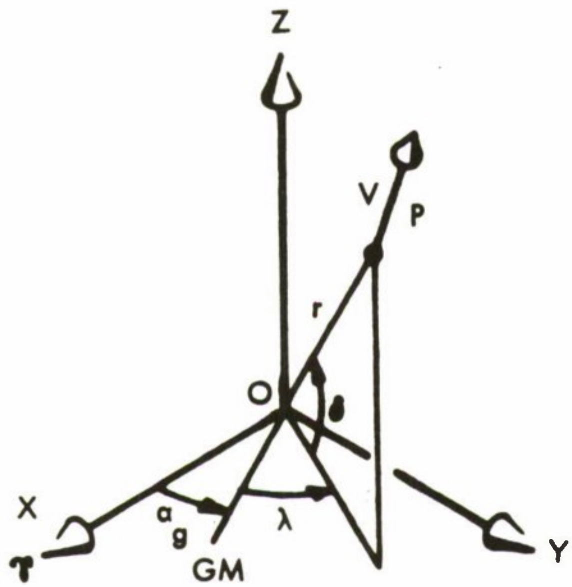
where V is a vector equal in magnitude and direction to the velocity of the body at point P, and where X is a vector from O in the equatorial plane directed to the true vernal equinox at 0.0h universal time on the day of epoch.

In P = P(α, δ, β, A, R, v)

- α is the right ascension of P
- δ is the declination of P
- β is the flight path angle measured positive downward from the geocentric vertical at P to the velocity vector
- A is the azimuth of the velocity vector measured positive clockwise from true north to the projection of the velocity vector in a plane normal to the local geocentric vertical
- r is the geocentric range to P
- v is the magnitude of the velocity vector, V.

6.3 GEOCENTRIC POLAR SPHERICAL (λDBARV) SYSTEM

The position and velocity of a body at point P are $P = P(\lambda, \delta, \beta, A, r, v)$



where

X is a vector from O in the equatorial plane directed to the true vernal equinox at 0.0h universal time on the day of epoch

α_g is the right ascension of the Greenwich meridian at time t

$$\alpha_g = \alpha_{go} + \omega_e (t - t_M)$$

α_{go} is the right ascension of the Greenwich meridian at time t_M

t_M is 0.0h universal time at day of epoch

ω_e is the rate of earth rotation.

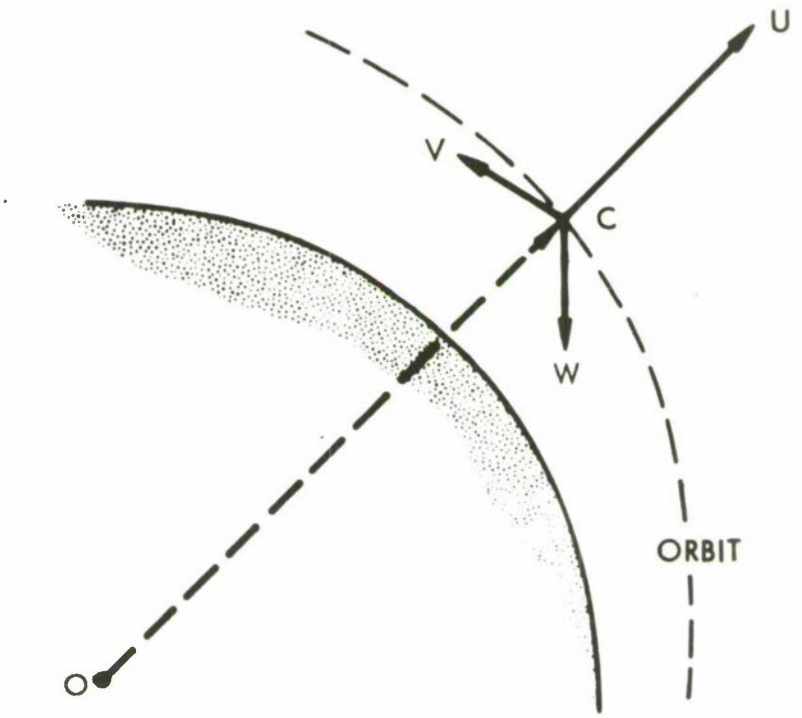
In $P = P(\lambda, \delta, \beta, A, r, v,)$

λ is longitude of P, measured positive eastward from the Greenwich meridian.

δ, β, A, r, V are the same parameters as defined in Section 6.2.

6.4 ORBIT PLANE (U, V, W) SYSTEM

Deviations in position and velocity of a body at C are C = C (u, v, w, $\dot{u}$, $\dot{v}$, $\dot{w}$)



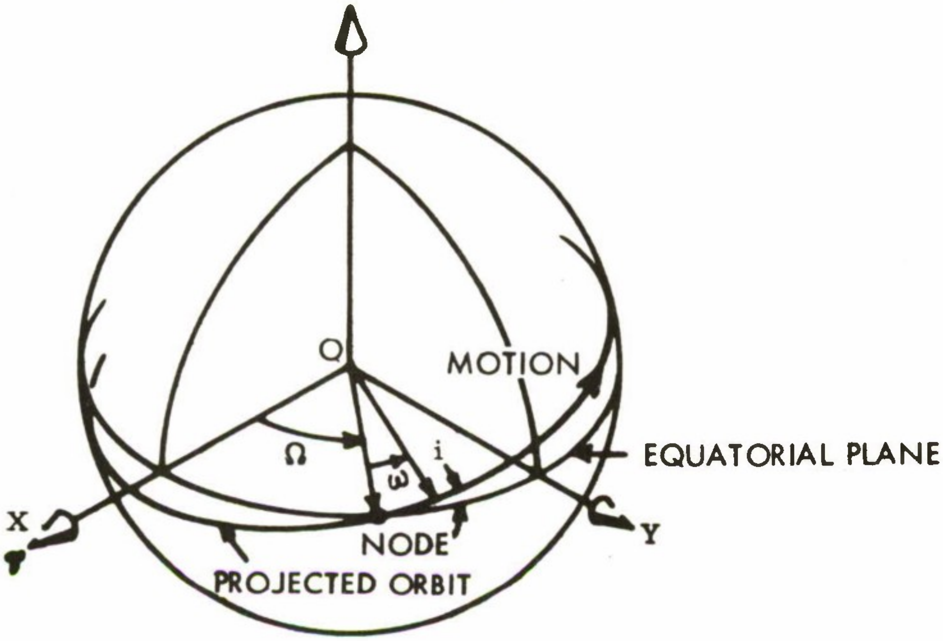
where

O	is the center of the earth
C	is the center of a body in orbit
U	is the vector from C collinear to a vector from O to C
V	is the vector from C perpendicular to U and lying in the orbit plane
W	is the vector from C which completes a right handed coordinate system

In C = C (u, v, w, $\dot{u}$, $\dot{v}$, $\dot{w}$), u, v, w are the components of the deviation in position of the body in the up, down, cross or u, v, w directions respectively; and $\dot{u}$, $\dot{v}$, $\dot{w}$ are its components of deviation in velocity in these directions.

6.5 OSCULATING CLASSICAL ELEMENTS

The position and velocity of a body at point P=P(a, e, i, Ω, ω, M). These elements are defined at the time associated with the Cartesian vectors of position and velocity. The osculating classical elements are referenced to the equatorial plane and the vernal equinox at 0.0h Greenwich mean time on the day of epoch. The elements are printed at each update time.



where

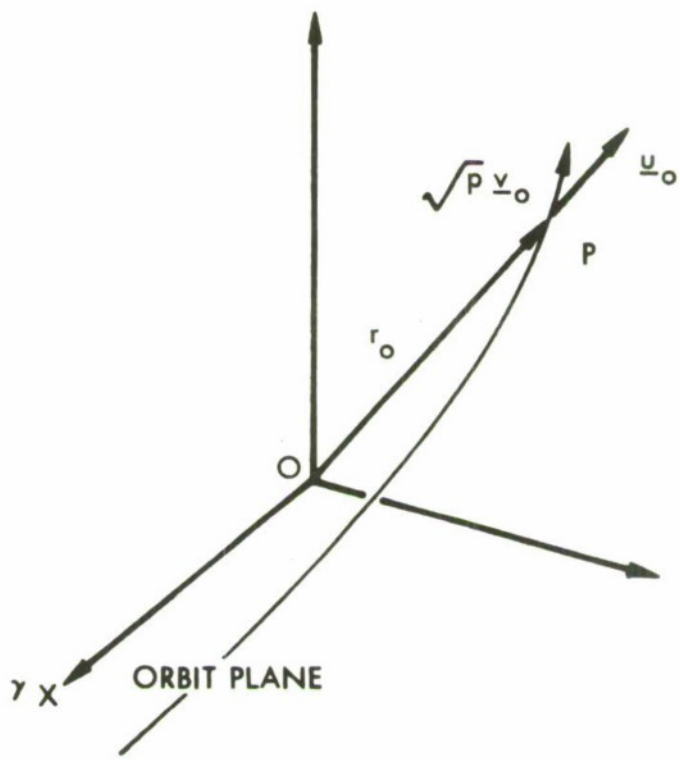
X is a vector from O in the equatorial plane directed to the true vernal equinox at 0.0h Greenwich mean time on the day of epoch.

In P = P(a, e, i, Ω, ω, M)

- a is the semi-major axis
- e is the eccentricity
- i is the orbit plane inclination to the equatorial plane
- Ω is the right ascension of the ascending node
- ω is the argument of perigee
- M is the mean anomaly

6.6 INDETERMINACY FREE ELEMENTS

The position and velocity of a body at point P are $P(1/a,\ r_o,\ \underline{u}_o,\ \sqrt{p},\ \underline{v}_o,\ D_o)$. These are called the indeterminacy free osculating elements at the given update times. They have been included to circumvent the indeterminacies which are inherent in the "classical set" $(a,\ e,\ \Omega,\ i,\ \omega,\ T)$ for certain types of orbits. For example: when $i = 0$, Ω is undefined; when $e = 0$, ω is undefined.



where

X is a vector from O in the equatorial plane directed to the true vernal equinox at 0.0h universal time on the day of epoch.

In $P = P(1/a,\ r_o,\ \underline{u}_o,\ \sqrt{p}\underline{v}_o,\ D_o)$

$1/a$ is the inverse of the semimajor axis

r_o is the magnitude of the position vector at the update time

$\underline{u}_o$ is the unit vector collinear with the position vector at the update time

$\sqrt{p}\underline{v}_o$	is the vector in the orbit plane, orthogonal to $\underline{u}_o$, with magnitude of the square root of the semi-latus rectum
D_o	is the scalar product of position and velocity vectors at the reference time

In order that a set of orbital elements be useful, it should provide a description of the orbit that is easily understood, as well as define position and velocity at epoch. Ease of two-body position and velocity prediction is also of importance. The indeterminacy free elements are useful because (a) they are determinate for all types of orbits; (b) they retain some descriptive value which is nearly equal to the "classical set," and certainly better than $\underline{r}_o$ and $\dot{\underline{r}}_o$; and (c) two-body position and velocity predictions are easily accomplished using a single set of equations.

The equations of condition on the unit vectors are as follows:

$$\underline{u}_o \cdot \underline{u}_o = 1$$

$$\sqrt{p}\underline{v}_o \cdot \sqrt{p}\underline{v}_o = p$$

$$\sqrt{p}\underline{v}_o \cdot \underline{u}_o = \underline{u}_o \sqrt{p}\underline{v}_o = 0$$

There are six independent orbital elements; i.e., nine elements related by three equations. The manner in which these elements reduce to the minimum set required to define each orbit type is detailed in Table 6.1

Table 6.1 Summary of Conditions Necessary to Define Each Orbit Type with Indeterminacy Free Elements

Orbit Type	Required Number of Elements	$\frac{1}{a}$	r_o	D_o	$\sqrt{p}\,\underline{v}_o$	$\underline{u}_o$	Total Elements	Equations of Condition
Circle	4	$a = r_o$		0			7	3
Ellipse	6						9	3
Parabola	5	0					8	8
Hyperbola	6						9	3
Rectilinear Ellipse	4			Derived from $\frac{1}{a}$, r_o	0		5	1
Rectilinear Parabola	3	0		Derived from $\frac{1}{a}$, r_o	0		4	1
Rectilinear Hyperbola	4			Derived from $\frac{1}{a}$, r_o	0		5	1

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13. ABSTRACT

This report describes the orbit determination programs and data processing programs developed by TRW Systems for the Lincoln Laboratory Millstone Hill radar. These programs provide the SDS 9300 computer associated with the radar with the following capabilities: satellite orbit prediction, antenna steering, data and editing averaging, and differential correction of the orbit elements. The programs that support the radar during a tracking operation are fully automatic, under the control of the radar hardware and the operator's console. They perform sufficiently fast to permit their use during a radar tracking pass and, thereby, provide real time orbit determination capabilities in supporting the tracker. This facility is accomplished by partitioning the orbit determination functions into those which can be performed before the pass, after the pass, and doing only the absolute minimum processing during the pass. The capabilities in the real time programs (MHESPOD) have also been provided in a stand-alone support program for nonreal time use (NRTPOD).

14. KEY WORDS

Millstone radar
SDS 9300
data processing

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